PLASMA PROCESSING UPDATE

A Quarterly Newsletter from Institute for Plasma Research

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MESSAGE FROM THE DIRECTOR

I am extremely pleased to announce the release of the 100th issue of our industry-focussed newsletter "Plasma Processing Update". The first issue of the newsletter was published way back in 1990, and we have come a long way since then. In its younger years, the newsletter was published as a hard-copy and was circulated through post. Keeping in tune with the times, it turned digital and is now published online.

The newsletter was initiated with the objective of propagating information about plasma processing activities of the Institute for Plasma Research (IPR). The purpose was also to reach out to local industry and to excite their interest in knowing more about Societal & Industrial applications of the fourth state of matter viz. Plasma. It was also intended to encourage industry to communicate with our scientists & engineers in a seamless manner. The newsletter has been playing a successful role in helping us receive many queries & visitors, leading to fruitful interactions. Some of these interactions have led to the birth of new ideas and technologies.

Over its long journey, the responsibility of publishing the newsletter was shared by many colleagues from time to time. Each one of them deserves our appreciation for their commitment. I would also like to thank the staff members for their contributions to the content of the newsletter. Last, but not least, I also take this opportunity to thank external experts who added value to our newsletter by writing articles from time to time. We will continue to strive to get better with each issue and highly value the feedback we receive from the readers.

I wish the newsletter to continue its journey for a long time to come.

Dr. Shashank Chaturvedi
Director, Institute for Plasma Research

MESSAGE FROM THE FOUNDING EDITOR

Plasma Processing Update: The Genesis

I am thrilled that we are celebrating the publication of the 100th issue of Plasma Processing Update.

I recall those days of early 1990. Aditya Tokamak entering a phase of routine operation made me start thinking of an activity which would allow me space for intuitive instrument building plus immediate practical use of knowledge gained through two decades of plasma physics at PRL and IPR in producing and manipulating a variety of plasmas. The fourth state of matter appeared to yield unique opportunities in high energy-density material processing with high-value addition. This led to the setting up of the Facilitation Centre for Industrial Plasma Technologies as IPR's bridge to the Industry.

The Plasma Processing Update was brought out to communicate all the exciting developments at Facilitation Centre for Industrial Plasma Technologies (FCIPT), a division of IPR; to industries. The first issue came out in 1990, written almost entirely by me. With time came new enthusiasts. After three decades, this newsletter is still going strong as an online journal, communicating to industries the developments in India on plasma processing and applications.

FCIPT has the unique distinction of being a path breaker in India in converting physics-based research into commercially and socially valuable devices and processes. The Department of Atomic Energy sees these societally relevant technologies as being of considerable developmental value. FCIPT shall realize its full potential with the setting up of the PlasmaTech Innovation Foundation to spin off its technologies through start-ups. This initiative will be timely and rewarding in the context of the Indian economy pursuing the *Make in India* and *Atmanirbhar Bharat* programmes in manufacturing and strategic spheres.

I wish the newsletter many years of bringing news of Plasma-based technologies to the Indian Industry.

Prof. P. I. John

Formerly Meghnad Saha Chair, Institute for Plasma Research

MESSAGE FROM DEAN (Administration)

Way back in August 1990, the first issue of "Plasma Processing Update (PPU)" was published by Institute for Plasma Research (IPR) highlighting emerging applications of plasma. A new chapter on applying fundamental research towards applications started in the country. Subsequent issues highlighted more and more applications of plasmas.

Then came 1997: a group of young scientists and engineers, ventured outside the research environment of IPR, to a centre located in GIDC Gandhinagar, to develop "plasma technologies for societal benefit". This newly made centre had to have a name which defined its purpose. It was named as "Facilitation Centre for Industrial Plasma Technologies (FCIPT)". FCIPT was an experiment by itself with its share of uncertainties, failures, rewards and successes. As a famous author once said, “When you want something, all the universe conspires in helping you to achieve it”; the same happened with FCIPT. Prof PI John, a very dynamic and visionary leader, led FCIPT in its formative years. The group of young scientists and engineers that ventured outside IPR in 1997, by then have started maturing and developing newer applications of plasmas. More staff joined FCIPT, leading to FCIPT being a vibrant place for doing research and applications. FCIPT now has patents, technology transfers, mentoring start-ups and various other activities - all with the aim to develop "plasma technologies for societal benefit".

It is indeed a great moment for us to celebrate the 100th issue of "Plasma Processing Update". Personally, I have been associated with FCIPT since 1997 and have greatly benefitted from this association. I wish FCIPT and the contributors to the 100th issue of "Plasma Processing Update" all success.

Dr. S. Mukherjee
Dean (Administration), Institute for Plasma Research
Former Division Head, FCIPT

MESSAGE FROM DEAN (R&D)

It is such a proud moment that our "Plasma Processing Updates" newsletter reaches a big milestone of 100th issue mark. This is the yardstick for the success of this newsletter. The newsletter helps to communicate information about plasma science and various applications of plasma technology to the students, science community, industry and even the general public. It provides regular updates on IPR's developed advanced plasma-based technologies and their commercialization for use in industry and other societal applications.

Hearty congratulations to all the authors for their invaluable contributions, over the long journey of the newsletter, which helped in enhancing its the technological and scientific substance. My heartfelt gratitude to the entire newsletter team for contributing their time and effort to the success of this newsletter.

Dr. Paritosh Chaudhary

Dean (R&D), Institute for Plasma Research

MESSAGE FROM DEAN (Academics)

It gives me great pleasure to witness that our "Plasma Processing Update" newsletter has reached its 100th issue, a big milestone that reflects its success. I am delighted to celebrate it. 'Plasma Processing Update' is a quarterly e-newsletter, published by FCIPT, IPR. This newsletter contains information on plasma processing activities of FCIPT, IPR; including scientific articles, news on technologies transferred, systems installed etc. The newsletter helps in communicating the latest information on the plasma processing activities of the institute to industries, the scientific community, universities etc. It is also playing an important role in attracting bachelor students from different external institutes/universities for their academic projects, and research scholars to take up research topics in the exciting field of applied plasma physics. Even post-doctoral fellows are also getting attracted to work in those plasma application-oriented fields. I am a regular reader of this newsletter and happy to tell you that along with the faculties, scientists, and engineers, the research scholars and post-doctoral fellows are also contributing to the newsletter with their research-based articles. I would like to congratulate the newsletter team for their commitment, dedication, and continuous effort to publish the newsletter regularly to make our society aware of our plasma-based activities and achievements, beneficial to the country. I wish the "Plasma Processing Update" newsletter to continue successfully for many more years to come.

Dr. Mainak Bandyopadhyay
Dean (Academics), Institute for Plasma Research

FROM THE EDITOR'S DESK

It is indeed very exciting that we are publishing the 100th issue of Plasma Processing Update (PPU), newsletter from Institute for Plasma Research (IPR). Its journey began long ago, in the year 1990, under the visionary leadership of Dr. P. I. John, the founding editor of the PPU. I gather, it originated with the idea of having a means to connect the plasma science & engineering community with the industry and to propagate the latest information on plasma processing for their benefit.

The newsletter has evolved over the years, reflecting insights and passions of several dedicated editors and their team. Each one of them has brought in his/her unique perspective and commitment to the periodic & successful publication of this newsletter, and all of them deserve great appreciation. We also thank all those colleagues and experts who have contributed articles for the PPU. Finally, this success wouldn't have been possible without the active engagement of our readers, through their feedback and queries. We extend our heartfelt gratitude to our readers.

In this milestone issue, it is emphasised to present an overview of some of the important technologies or activities (having societal/industrial significance), that IPR has developed/ working-on at present. Only for the convenience of readers, these articles are classed into four different categories. However, for specific and latest information, please feel free to contact at ptts@ipr.res.in.

Wishing greater success to the newsletter with many more issues to come.

Happy reading.

Satyaprasad Akkireddy
Editor, Plasma Processing Update
Institute for Plasma Research

Editorial Team
Satyaprasad Akkireddy
Kushagra Nigam

A Vision for Plasma Processing for India

P I John

Ex. Senior Professor, Institute for Plasma Research, Gandhinagar

Introduction

Plasma processing underwent a momentous transformation in the late 1990s when the nonequilibrium plasma was liberated from its vacuum environment. Suddenly the cold plasma torch became a plaything and attracted biologists, agricultural scientists and medical research people to experiment with it and find applications widely outside the field of conventional plasma processing. The paradigm in plasma physics: New plasmas mean new plasma physics and applications was well substantiated with the invention of atmospheric pressure cold plasmas.

Plasma in liquid is an emerging field. We do not even know how the plasma gets formed. Two opposing plasma-initiating mechanisms were postulated for voltage-induced breakdown at a submerged electrode. One school of thought suggested electrical discharge to be generated purely by electric processes in the liquid phase. According to the rivalling bubble mechanism, plasma initiation occurs in a gas phase, i.e. a bubble. The fundamental dilemma is – which comes first: plasma or bubble? In other words, does ionization precede evaporation or vice versa?

Plasma processing is still a dynamic field with activities in many applications. But four drivers seem to be setting the pace. These are Global warming and climate mitigation, Environmental remediation, Hydrogen Economy and the extension of Moore's Law in semiconductor chip fabrication. What is true globally is also true for India. A few years ago, the last of the drivers, namely plasma processing for silicon chip manufacturing may not have been relevant for India. The recent address by Prime Minister Narendra Modi in the SEMICON India 2024, clearly highlights India's ambition to become a global hub for semiconductors, showcasing the nation's growing role in the industry. He highlighted that India has attracted Rs 1.5 trillion in investments.

Plasma-mediated CO_2 Reforming

There is great activity in CO_2 reforming to help climate mitigation. Technologies for extraction of CO2 from the air and converting it into synthetic organic chemicals including fuel are already in place. By recapturing and reusing the CO_2 emitted, the CO_2 cycle is closed, establishing an equilibrium condition. The net emission will be zero. This mimics the carbon cycle of the Earth, which has been in near equilibrium for millions of years. The clear benefit is that it allows us to continue using the existing infrastructure for hydrocarbon energy storage, transport etc. This makes CO_2 the ultimate fuel, as start-up activity in this led by Bill Gates and people with technological foresight show. Non-equilibrium Plasma-chemical Reactor which drives a variety of conversion reactions is an interesting variant on the current non-plasma processes. Both the conversion efficiency and the throughput are targets for improvement. Microwave plasmas and gliding arc plasmas seem to be the favourites. The products are synthetic hydrocarbon fuel and chemicals. The fuel can be stored in the gas grid in the form of chemical energy.

In the context of the plasma chemical reactions driving CO_2 conversion and Hydrogen enrichment, a relatively unexplored area is the plasma catalytic enhancement of these processes. This is an area worth pursuing.

Catalysis describes a process in which the rate and/or the outcome of the reaction is influenced by the presence of a substance which is the catalyst that is not consumed during the reaction. In traditional thermal catalysis, molecules are dissociatively adsorbed onto the catalyst with the energy being supplied in the form of heat. In plasma-assisted catalysis, species are activated by the plasma due to excitation, ionization or dissociation by electrons in the gas phase or on the catalyst surface. Plasma catalysis is best regarded as conventional catalysis perturbed by the presence of a discharge, which modifies its operating conditions, properties and outcomes often in a very localized way. The description "plasma-activated catalysis" is an apt one. The catalytic process is complemented using plasmas that activate the source gas. This combination is often observed to result in a synergy between plasma and catalyst.

The combination of plasma and catalysis is of great interest for plasma-mediated Carbon Dioxide dissociation. The combination has synergistic effects like promotion of catalyst activity at reduced temperatures causing a significant reduction in the energy cost for activating the catalyst. The synergistic effect can be attributed to the dominant catalytic surface reaction driven by energetic electrons from the CO_2 discharge. CO_2 dissociation processes were significantly enhanced by the presence of oxygen vacancies.

The reported effects of the plasma on the catalyst include changes in its physicochemical properties, such as a higher adsorption probability at the catalyst surface, a higher catalyst surface area, a changed catalyst oxidation state etc. The resulting interactions when combining a plasma with a catalyst for plasma-based CO_2 conversion often yield improved process results in terms of conversion, selectivity, yield and energy efficiency.

Plasma Gasification for Waste to Energy Conversion

Energy recovery from plasma gasification was an area we had started working on earlier but did not proceed further. We injected the gasification product after essential filtering into a diesel generator and produced 12 kW of power. We did not proceed with this further since for the medical waste treatment plants we were developing at that time, it did not seem to be a priority. But the situation is quite different now. Following the submission of a report on Waste to Energy by a high-level task force in 2014, Niti Aayog has set a target of constructing 511 MW of WTE plants by for 2018–19 under the Swachh Bharat Mission (SBM).

A niche area in the WtoE field is compact biomass waste gasification. On supply of heat, biomass breaks down into small molecules. A predominant part is CO and Hydrogen, which form the Syngas. At present, there are three enablers for a focused thrust on promoting biomass plasma gasification. These are:

1. Waste to energy concept is gaining ground.
2. Indigenous, small-scale gasifiers which generate electricity from biomass are being built to treat agricultural biomass by a number of manufacturers.
3. Microwave torches have been developed at FCIPT. Microwave plasma gasification would be ideal for such applications because of the high syngas component in the product gas as a result of the higher electron temperature.

Plasma-mediated Hydrogen Production

A major opportunity for plasma processing exists in the on-going Hydrogen Mission. Because of the safety issues associated with Hydrogen storage, compact, portable Hydrogen sources are of great advantage in Hydrogen applications in transport. In the case of distributed hydrogen production from gaseous fuels: gliding arc and microwave discharges are the preferred plasma configurations. These are new types of plasmas that we have to learn about. These can be based on fuel-reforming reactions using non-equilibrium plasmas. Our know-how on plasma pyrolysis will be of value here. Here too, plasma catalysis is a popular path for increasing performance parameters.

Plasma Reactors for Semiconductor Process Skilling

In Silicon chip processing, we may be able to contribute in a unique way. With several Fabs coming up into production in a few years, India will need 12 lakh manpower in semiconductor-related industries by 2032, according to a report by the Semicon India Future Skills Talent Committee set up in August last year. Several higher educational institutions like the IITs have developed ambitious programmes of manpower training. Skilling will require exposure to plasma processing techniques like etching, coating, PECVD etc. FCIPT is in an excellent position to supply this equipment to organizations which are planning the skilling activity.

IPR's Atal Incubation Centre (AIC): A Step Closer to Nurturing Technology-based Startups & Effective Technology Translation & Transfer

Nirav Jamnapara
Institute for Plasma Research

Institute for Plasma Research (IPR) works on its primary objective of realizing magnetic confinement fusion for energy sustainability. As a spin-off of the vast knowhow so generated from this research on plasma science & technology, IPR had been addressing several societal needs using plasma based innovations since 1997, thereby bridging the gap between institute and industry. The Facilitation Centre for Industrial Plasma Technologies (FCIPT) was established in 1997 in a separate premises to ensure that such societal and industrial research reaches the market through active involvement of users and industry. Statistics indicate that IPR has so far (2005 onwards) executed around 81 sponsored projects worth ~ Rs. 38 Crores which involves technology transfer, R&D service and new product delivery.

In the last few years, the Government of India has laid strong emphasis on strengthening the country's economy through reinforcement of MSME industries and through startup ecosystem. As a result, the deeptech startup ecosystem has achieved traction and is envisaged to significantly contribute to the country's technological strength. The Government of India's mission of 'Atmanirbhar Bharat' has also provided significant boost to domestic manufacturing capabilities.

The Department of Atomic Energy sensed the need of strong technological and R&D support required to boost deeptech startup innovation in the country. Therefore, in May 2020 the Government of India announced reforms in the Atomic Energy Sector with public private partnership (PPP) mode interaction and through establishment of technology business incubators at several research institutions of DAE. Consequently, IPR's incubation centre was launched in Oct 2021 followed by formation of DAE incubation policy in Feb 2022 and recognition of IPR's incubation centre as Atal Incubation Centre in Jan 2023.

The Atal Innovation Mission of NITI Aayog mandates all its incubators to be registered as a special purpose vehicle so that adequate autonomy enables disruptive innovations from the available technological expertise at IPR. This autonomy is necessary to take local and prompt decisions related to deeptech startup ecosystem such as equity sharing, technology translation, new businesses related to advanced technologies, seed funding, conducting training, hackathons and other such events etc.

IPR thus, with the approval of DAE established AIC-IPR PLASMATECH INNOVATION FOUNDATION as a company under section 8 of companies act 2013, in December 2023 with 100% ownership of the Department (DAE). This company shall act as an interface between IPR and the industry thereby facilitating translation and transfer of advanced technologies to Indian industries. The company (AIC-Plasmatech) primarily aims to nurture and support deeptech startups. IPR, as a host institution, has committed providing required land/space and infrastructure for the AIC and for providing technological expertise to startups. The company's objectives are:

- To establish high class advanced incubation facility and provide support to startups and the entire startup innovation ecosystem.

- To provide technology access, support and transfer in several domain areas of IPR's expertise.
- Conduct events, workshops, hackathons, ideathons, pitch decks etc. as needed.
- To undertake training & capacity building programmes as needed, mentoring support to startups etc.
- To facilitate & encourage creation of new technologies and expertise and incentivise technology developers and mentors suitably.
- To act as technology translation wing of IPR, DAE by facilitating technology transfer & licensing, design, consultation, equipment development & supply, feasibility studies, product & process development etc.
- To collaborate with industries on areas of mutual interest.
- To facilitate PPP mode collaboration with industries and to undertake CSR & SSR related projects.

Recently, the company AIC-Plasmatech has reviewed and shortlisted nine technology based startups to be incubated, out of which three were onboarded on the day of its first Annual General Meeting held in September 2024.The three startups onboarded are:

1. *M/s Ecoplaswa Technology Pvt. Ltd., Ahmedabad for Plasma Activated Water technology to be used in Dairy tech / Agri tech sectors.*
2. *M/s Exxcarbon Pvt. Ltd., Bangalore for RAUDRA Plasma Pyrolysis/Gasification technology to be used for waste-to-energy applications.*
3. *M/s LBIS Research Pvt. Ltd., Ahmedabad for Plasma assisted glass like barrier coating on biodegradable food containers.*

Another batch of six startups are to be onboarded this year while six more startups are under screening/review for further consideration. All the selected startups will get the access to IPR's state of the art infrastructure, technological expertise, mentoring and technology transfer apart from regular incubation services such as business support, investor pitching, office/seating etc. Additionally, AIC-Plasmatech has also collaborated with an MSME industry (M/s Cenerge Engineering) for design of cryopanels through a formal contract.

The Plasmatech Innovation Foundation shall be funded by Atal Innovation Mission, NITI Aayog for a period of 5 years with a budgeted amount of Rs. 10 Crores. In the meantime, the AIC shall aim to become a focal point on deeptech innovations in the country and across the Globe.

Any student or individual or a startup company having a technological startup idea matching IPR's expertise domain can contact us at ptts@ipr.res.in with a copy to incubation@ipr.res.in.

In this section, details of the fully developed technologies are presented. These technologies are tested for their performance & reliability, and are ready for commercial deployment. Many systems were supplied to & installed at several institutes or companies. Most of the systems described in this section are scalable, reliable, safe and found to meet the necessary regulatory and statutory norms. The technology know-how has been transferred to many licensee partners. For more specific and complete details please contact ptts@ipr.res.in.

PLASMA PYROLYSIS

Plasma Pyrolysis Technology (RAUDRA) for Safe Disposal of Waste

Introduction

Demand for safe disposal of waste is increasing all over the world. Safe disposal of contaminated and infectious hospital waste requires a technology that provides a complete solution i.e. to sterilize the waste as well as to reduce its volume or mass substantially without releasing toxic emissions in to environment. Incineration is one such technology that partially fulfils above criteria and takes care of sterilization and volume reduction. However it requires excess air in the primary chamber for burning of the waste. It has been observed that the excess air that is added for complete combustion, limits the temperature that could be obtained in the primary chamber of incineration system. Due to insufficient temperature generated in the process chamber, there is more probability that incinerators produce extremely toxic products such as furans and dioxins. These compounds may cause cancer and also create various abnormalities in the body.

Plasma pyrolysis is an able alternative to the conventional incineration technology. It is an advanced waste treatment technology that utilizes high-temperature plasma to dispose organic materials, in an oxygen starved environment. In this process, plasma torch generates extreme heat which helps in the thermal disintegration of organic compounds into simpler molecules and also to convert them into useful by-products like syngas, a mixture of hydrogen and carbon monoxide etc. Almost 99% of organic mass gets converted into combustible gases in this process. These by-products can be used for heating applications and energy production. Further, highly toxic molecules like dioxins and furans are completely eliminated in this process making it an environment friendly process. Plasma pyrolysis offers several advantages including reduced emissions, minimal residue, its ability to process various types of waste, possibility of energy recovery etc. making it a promising solution for waste management.

Brief history

In early 1990s, plasma pyrolysis has emerged as a technology in the world, which seemed to provide a complete and safe solution to destroy medical and other hazardous waste. In USA, Solena, Wastinghouse, PEPS, PEAT and a few other companies have demonstrated plasma pyrolysis technology as a better solution for safe destruction of a variety of waste stream. In-Flight Plasma Arc System was designed by Plascon, Australia, to treat chlorinated organic compound in which the destruction efficiencies of better than 99.99% were achieved while keeping the dioxin and furan content much below the standards set by US EPA (United State Environment Protection Agency). Recently, PEAT International has commissioned one plasma arc based waste disposal unit at Shanghai, China, that disposes 60 kg per hour of biomedical waste and oil refinery sludge.

Development of Plasma Pyrolysis Technology at Institute for Plasma Research (IPR)

Plasma pyrolysis is an advanced technology wherein 'high temperature' and 'oxygen starved environment' are utilized for thermal disintegration of organic compounds and for safe disposal of waste. IPR had initiated work on developing the plasma pyrolysis technology way back in 1998. Plasma pyrolysis system comprises of various subsystems such as plasma torch, primary chamber, secondary chamber, venturi and secondary scrubber, demister, electrostatic precipitator, cyclone separator, ID fan and chimney. A schematic diagram of this system is shown in figure 1. Plasma torch is the work horse in plasma pyrolysis system which maintains the required high temperatures in the primary chamber, by efficiently converting electrical energy into thermal energy. After carrying out many experiments and optimization studies, IPR could initiate building of a proto-type plasma pyrolysis system by 2002, with financial support from Department of Science and Technology (DST), New Delhi. Within two years after that, IPR had installed & commissioned its first plasma pyrolysis system (15 kg/hr) in 2004, at Goa Medical College, Bombolim, Goa, for safe disposal of solid and biomedical waste. This system could demonstrate the successful operation of pyrolysis system by

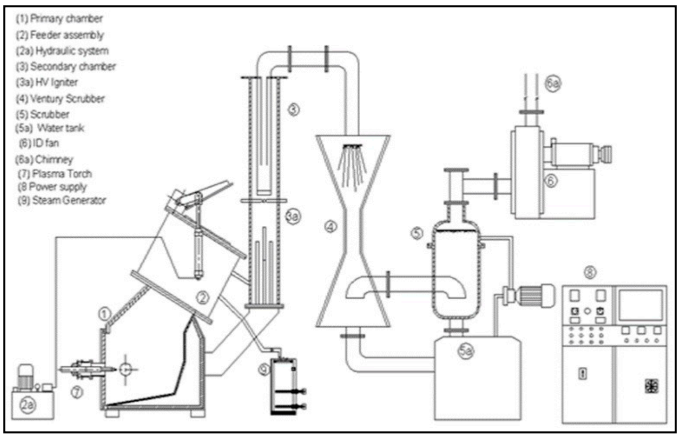

Figure 1: Schematic diagram of Plasma Pyrolysis System

disposing more than four tons of biomedical waste in the year 2004-2005. Photograph of the installed system is shown in figure 2. This activity was also financially supported by DST. Since then, IPR has installed & demonstrated 11 systems at various locations in India, for disposal of solid and biomedical waste. Subsequently, IPR has also developed and demonstrated a higher capacity plasma pyrolysis system (50kg/hr), ensuring its compliance with emission norms set by US-EPA, and Central Pollution Control Board (CPCB), India. CPCB and Ministry of Environment and Forest & Climate Change (MoEF & CC) have given approval for using the plasma pyrolysis system, in India, for safe disposal of biomedical waste (yellow bag which may contain human/animal anatomical waste, soiled waste, expired or discarded medicine, biological chemicals), through publishing in Gazette of India "REGD. S.D.L. 33004/9; No. 197 dated 28 March 2016". This indigenously developed technology can provide a better environment friendly solution to the waste disposal problem in India as well as in the world.

Figure 2: 15kg/hr. Plasma Pyrolysis System installed at Goa Medical College, Bambolim, Goa

Emission Measurements

IPR had conducted several emission analysis tests, in plasma pyrolysis systems installed at various locations in India, in order to demonstrate the ability of plasma pyrolysis technology in safely disposing the waste in an environmental friendly manner. This exercise was also funded by DST. The emission test results are presented in table 1. Results clearly indicate that the emissions from the system are well below the norms stipulated by CPCB.

Table1: Emission test results of Plasma Pyrolysis System

Pollutant	CPCB standards	Emissions from Plasma Pyrolysis System
CO	≤ 100 mg / Nm^3	40-85 mg / Nm^3
NOx	≤ 400 mg / Nm^3	7-25 mg / Nm^3
PM	≤ 50 mg / Nm^3	31-52 mg / Nm^3
Dioxins & Furans	≤ 0.1 ng / Nm^3 TEQ*	0.01-0.1 ng / Nm^3 TEQ

* TEQ = Toxic Equivalent

Demonstration of 1 Ton/Day (TPD) Plasma Pyrolysis System

IPR had also developed and successfully demonstrated a higher capacity (1 TPD) plasma pyrolysis system with DST funding. Photograph of the system is shown in figure 3. Several experiments and research activities were carried out in this system to demonstrate the safe disposal of various types of waste streams which include simulated biomedical waste (60% cotton +30% plastic +10% moisture), tannery industry waste, mixed solid waste, petroleum industry waste, chemical industry waste etc. It was observed that in all the cases, the emissions were well within the norms prescribed by CPCB. This system installed at FCIPT, is utilized for conducting feasibility studies, data generation etc. by using different types of waste streams at various operating parameters.

Industrial Scale 5 TPD Plasma Pyrolysis Plant for Disposal of Biomedical Waste

At present, IPR is working on developing an industrial scale plasma pyrolysis system/plant with 5 TPD capacity and it is fully funded by Department of Atomic Energy (DAE). This system is going to be installed at Common Biomedical Waste Treatment Facility (CBWTF), which is being established at Ramana Village in Varanasi, Uttar Pradesh. CBWTF is expected to handle the waste generated from 10,000 beds from different hospitals located in and around Varanasi. IPR, MPMMCC (Mahamana Pandit Madan Mohan Malviya Cancer Centre), Varanasi, and Varanasi Municipal Corporation are jointly working to establish this facility. A variety of waste treatment systems will be housed in this facility, in order to take care of all four categories of biomedical waste. 5 TPD plasma pyrolysis system, which is being developed by IPR, is one of these waste treatment systems which would be handling the yellow category infectious biomedical waste. Graphical image of this plant's design is shown in figure 4. Some of the subsystems of this pyrolysis plant have arrived at IPR and a few others are getting fabricated at present. The entire system will be assembled at IPR and will be tested here for its overall functionality, using simulated waste. Later it

Figure 3: 1 Ton per Day capacity system developed at IPR

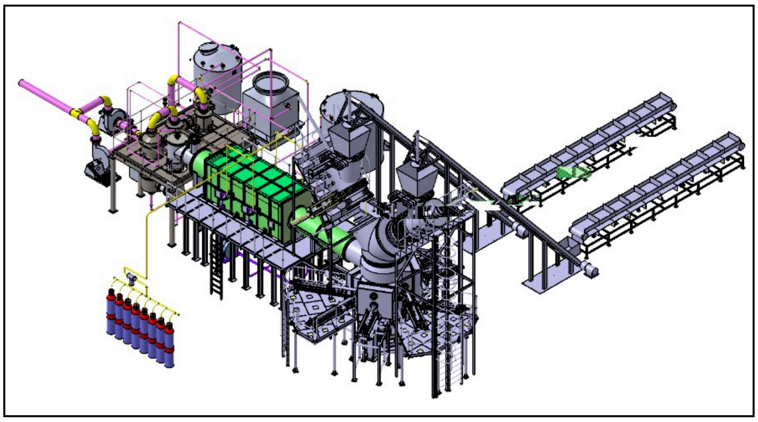

Figure 4: Isometric (schematic) view of 5 TPD Plasma Pyrolysis plant

will be shifted to CBWTF, Varanasi. The successful demonstration of this system at Varanasi will motivate the facilitators to use this environment friendly technology in all major cities in India.

Conclusion

Plasma pyrolysis technology is a promising solution for waste management, offering an efficient and environmental friendly alternative to conventional waste disposal methods. It has been included in the Gazette of India published by MoEF & CC as alternative technology to incineration for the disposal of biomedical waste. Energy recovery from organic waste (papers, plastics, oil, petroleum industry waste etc.) is possible with plasma pyrolysis. It does not produce toxic emissions during disposal of different types of wastes. The capital cost is relatively high when compared to the conventional technologies, however the operational cost is at par with them. Increasing the awareness of plasma pyrolysis technology and its advantages among technocrats & people will help in will help in penetration of the technology in to market. On the other hand, strict implementation of environmental norms by government agencies will popularize this pollution-free plasma pyrolysis technology as one step solution for waste management.

Technology Transfer

The plasma pyrolysis technology has been transferred to six Indian companies on non-exclusive basis. Successful demonstration of 5 TPD plasma pyrolysis plant will boost the confidence of the facilitators for using this home-grown technology.

Suggested Reading

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Plasma Nitriding: A Sub-atomospheric Surface Hardening Process

Introduction

During the fabrication of industrial metal parts, manufacturers frequently seek to harden the exterior of steel components to enhance their wear resistance. Several technologies are available to achieve the surface hardening, including carburizing, induction hardening and nitriding. Nitriding involves the diffusion of nitrogen across the surface of steel components in order to harden their outer layers. At high temperatures, nitrogen will combine with alloying elements present in ferrous metals to form hard nitrides. This process creates a harder exterior which resists abrasion more effectively. Nitriding can be carried out using liquid, gas and plasma medium. In plasma nitriding, in contrast to liquid and gas hardening processes, the components are treated at significantly lower temperatures, which ensures reduced thermal distortion and high dimensional accuracy of the components. This benefit results in saving the additional cost that would otherwise require for reworking of the treated components. Plasma nitriding allows for easy control of the layer structure, which must have a very limited thickness or must be without compound zone (CZ-white layer) of nitrides. In addition, plasma nitriding can also be applied to those steels with shallow range of tempering temperature, without losing their core strength. Further, plasma nitriding is unique because of its reproducibility, environmental friendliness, and energy efficiency. Plasma nitriding finds numerous applications in the fabrication industry of high-tech industrial components. The ability to harden metal surfaces selectively and uniformly offers great utility to manufacturers in a multitude of industries. A photograph showing typical plasma-glow around the industrial components being treated in a reactor developed at Institute for Plasma Research (IPR), is shown in figure 1.

Industrial components that are typically plasma nitrided include gears, crankshafts, camshafts, cam

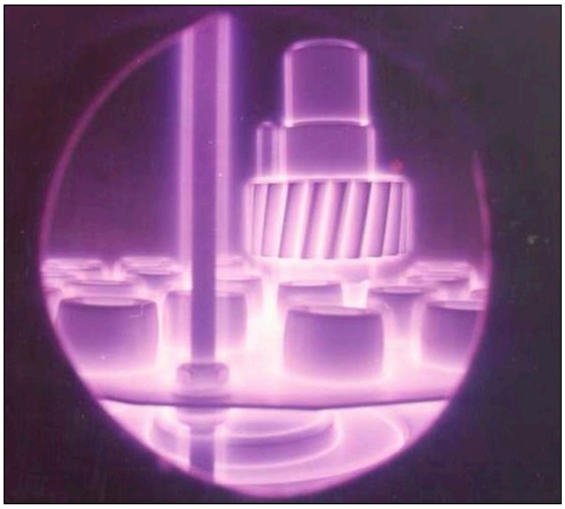

Figure 1: Plasma glow around gears and other components during plasma nitriding

lifters, valve parts, extruder screws, die casting tools, forging dies, cold forming tools, injectors, plastic forming tools, long shafts, axles, couplings, and engine parts. Plasma nitriding is suitable for treating all ferrous materials, sintered steels, cast iron, and high-alloy tool steels, even with chromium contents above 12%. Stainless steels and nickel-based alloys can be plasma nitrided and retain most of their corrosion resistance at low temperatures. Plasma nitriding of titanium and aluminum alloys is a unique application.

Development of Plasma Nitriding at Institute for Plasma Research (IPR)

Plasma Nitriding is one of those technologies that IPR has started to work on, almost four decades back. In 1996, the first system, a cold-wall plasma nitriding reactor was developed. However, in these reactors as plasma energy is spent on both 'heating' and 'nitriding' of the components', it was not possible to independently control the temperature and nitriding intensity. There were also limitations on the range of voltage and current that could be used for achieving the desired nitride layers. Hence, in order to overcome these limitations, a next generation hot-wall plasma nitriding system was developed (figure 2) which ensured optimal nitriding quality by achieving the highest demands on temperature and nitriding process control. The advantage of this reactor is to have an independent control over 'heating' and 'plasma nitriding parameters'. IPR has developed process recipes for nitriding more than 25 types of steels. After gaining

Figure 2: Prototype hot wall Plasma Nitriding Reactor

experience in operating plasma nitriding reactors, IPR has also developed a large plasma nitriding reactor (of 2m height and 1.5m diameter) for job-shopping (figure 3). This system was operated on chargeable basis, with no profit. Most of the local industries from various sectors like dies, textile

Figure 3: Industrial scale Plasma Nitriding Reactor for job working.

components, cranks shafts, gears and pinion of spacecraft got the benefit of treating their components in this reactor.

IPR has licensed the indigenously developed plasma nitriding technology to three industries in India. IPR has also installed & commissioned Plasma Nitriding systems at more than ten locations in India (industries and universities). Figure 4 shows an industrial scale plasma nitriding system installed at Central Tool Room (CTR), Ludhiana; by one of our Industrial tech-transfer partners.

Figure 4: Plasma Nitriding system installed at CTR, Ludhiana by our licensee partner.

At present, a large plasma nitriding system (3m height and 1m diameter) is being installed at FCIPT, IPR which will eventually be operated by an external agency through Government operated company operated (GOCO) mode. A photograph of this system is shown in figure 5.

Figure 5: Plasma Nitriding system to be operated in GOCO mode.

Non-Thermal Air Plasma Technology for Eco-friendly Processing of Textiles

Introduction

The conventional wet-chemical surface treatment process in the textile industry uses huge amounts of water and polluting chemicals. Reportedly, on an average 150 litres of water and 90 M Joules of energy is used for processing of 1 kg of Fabric. The waste water effluents from textile industry contains dyes, pigments, acid, alkali salt and other chemicals that are hazardous for the environment. Thus, there is a need for environment friendly green technologies in Textile Processing. In this context, the plasma processing is an environment friendly and dry technique that has shown its potential for surface modification of fiber, yarn or fabric in various processing applications. Institute for Plasma Research (IPR) has developed many indigenous atmospheric pressure non-thermal air plasma processing systems for various textile surface treatment. These plasma systems are particularly useful in textile processing which require surface activation and/or removal of impurities which in turn can be used in improving textile properties such as cohesion/adhesion, shrink resistance, wettability, surface energy etc.

Plasma textile treatment system for Angora Wool processing

Angora wool obtained from Angora rabbit is extremely fine, warm, soft and silky to touch. However, the spinning of Angora wool is not possible due to its highly smooth surface and slippery nature. The Angora wool is therefore blended with other fibers in order to improve its spinnability. However, this blending of other fibers leads to lowering of the quality of final product. In order to overcome these problems of Angora fibre, IPR has developed an eco-friendly 'Atmospheric Plasma Processing System'. The plasma treatment of wool generates nano-scale roughness on the surface of its fiber, which improves the cohesion among fibers and thereby facilitates spinning. FESEM images showing surfaces of both treated and untreated Angora wool fibers, at high magnification, is shown in figure 1. It is observed that, after plasma treatment, weaving and spinning is possible even with 100% angora wool, and also that there is no shedding of the fibers from wool product [1-4]. Further, cost of the plasma treatment works out to be around 40 Rs./kg only and this makes cost of Angora wool products comparable to Pashmina wool products.

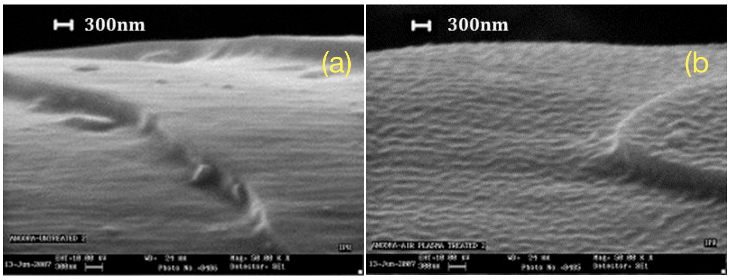

Figure 1: FESEM image of Angora wool fiber (a) Untreated (b) Plasma treated

IPR has installed many plasma treatment systems and one of them is shown in Figure 2. This system was actually synchronised with the carding machine for making 1 meter wide web of Angora wool for inline treatment and the plasma treated web was

Figure 2: Atmospheric pressure air plasma system for Angora wool treatment

converted in to sliver. Such systems for Angora wool treatment were installed & commissioned at Himalayan Institute for Environment Ecology (HIFEED) Ranichauri; Kullu Weavers & Development Corporation (KWCIS), Kullu and Sikkim Handicrafts & Handloom Development Corporation (SHHDC), Sikkim.

Plasma Treatment System installed at MANTRA, Surat.

Air plasma treatment induces nano-scale roughness on polymeric substrates and hence can be useful in improving its adhesion with other surfaces or coatings. A plasma treatment system for improving adhesion of PU/PVC coatings on the polyester fabric has been developed for Man Made Textile Research Association (MANTRA), Surat. Photograph of the installed system is shown in figure 3.

Figure 3: Atmospheric Pressure Air Plasma system installed at MANTRA

Cotton pre-treatment using air plasma

Raw Cotton or Grey Cotton is hydrophobic in nature and not suitable for dyeing or printing due to presence of non-cellulosic impurities such as natural oil, waxes, pectin and coloring matter on the surface of its cuticle and primary wall. Plasma treatment is observed to be useful in removing these organic contaminants from its surface and improves its wettability [5]. FESEM images of both untreated and treated Cotton fiber are shown in figure 4. A photograph demonstrating the improved wettability of a plasma treated khadi cotton fabric is shown in figure 5.

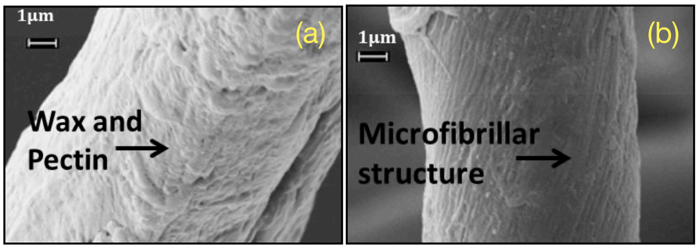

Figure 4: SEM image of Cotton fiber (a) Raw (b) Plasma treated

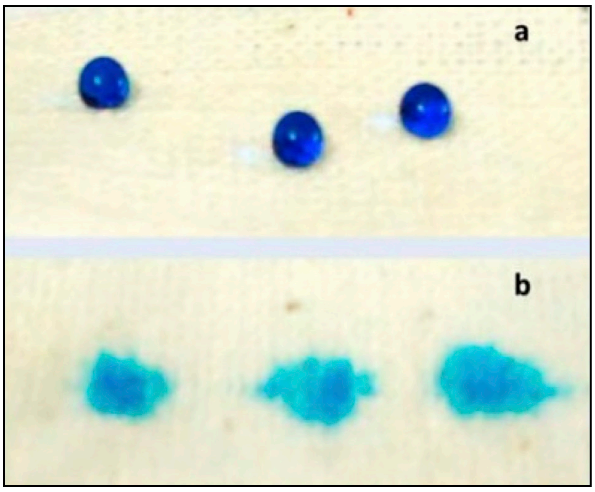

Figure 5: Ink droplet on Khaadi Cotton Fabric (a) Raw (b) Plasma treated

Plasma Treatment System for inline treatment of 2.5 meter wide textile at moderate speed

IPR has also developed an industrial scale plasma treatment system in which high density uniform glow discharge can be generated over a large area, in ambient air and at atmospheric pressure. A photograph of the system is shown in figure 6. A low cost novel power source has been developed for this purpose [6,7]. This system generates uniform air

Figure 6: Industrial scale Plasma System for 2.5 meter wide textile

plasma over a large area using multiple pairs of DBD electrodes and can handle 2.5 meter wide textiles, and thereby satisfying the inline treatment requirements of textile industry. This system is capable of treating textiles at a maximum speed of 20 meters/minute, and minimum cost of 60 paisa per square meter.

Using this high density plasma discharge system, experiments were carried out to study and improve shrink resistance properties of wool. The results show that just 10 seconds of plasma treatment has considerably improved its wettability, thereby improving its shrink resistance [8]. Morphological studies, using FESEM, indicate that the plasma treatment has changed the sharp cuticles (on fiber surface) in to blunt ones (figure 7).

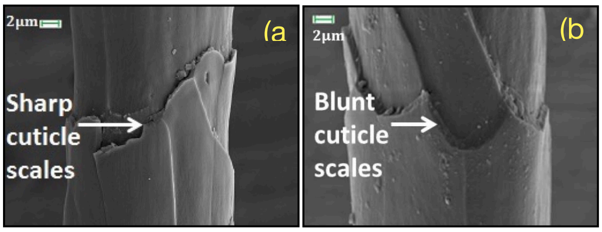

Figure 7: FESEM images of Merino wool fiber (a) Untreated (b) Plasma treated

Recently, IPR has also developed an inline plasma treatment system for surface modification of high density polyethylene. This system was installed & commissioned at Central Institute for petrochemical engineering and technology (CIPET), Ahmedabad. Detailed experimental study shall be carried out by CIPET for successful demonstration of adhesion improvement in Geo-membrane applications. Photograph of the developed system is shown in figure 8.

Figure 8: Atmospheric Pressure Plasma System developed for CIPET

Conclusion

Atmospheric pressure air plasma has high potential as an eco-friendly alternative for textile applications where surface ablation/etching, organic contaminant removal and surface activation are required. However, in order to achieve results at par with the conventional wet-chemical processes in few of applications such as cotton scouring, wool shrinkage etc. sustainable hybrid processes involving plasma and other technologies are needed. Further collaborative support from textile industries/ institutes can promote the industrial usage of this eco-friendly technology.

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Plasma Activate Water and its Applications

Introduction

Conventionally, inactivation of pathogens and bacteria is done by using chemicals such as alcohols, Dettol, fungicides, pesticides etc. which are harmful to human beings, and they are costly as well. Plasma activated water (PAW) is gaining significant attention in the past two decades due to its enormous potential in inactivation of pathogens such as bacteria, fungi, virus, and pest etc., and also due to its cost effectiveness. Furthermore, it finds potential applications in improving seed germination and plant growth, food preservation, and inactivating cancer cells etc. Formation of PAW in nature and lab is pictorially depicted in figure 1a and 1b respectively. The aforementioned prospective applications of PAW can be attributed mainly to its physicochemical properties such as pH, reactivity (oxidation-reduction potential), and electrical conductivity, etc.

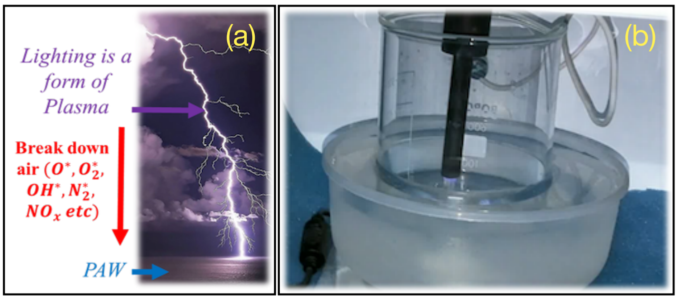

Figure 1: Formation of Plasma Activated Water in Nature and in the Laboratory

At Institute for Plasma Research (IPR), we have developed a facility to produce PAW using Pencil Plasma Jet (PPJ) [1-2], as well as by employing dielectric discharge (DBD) apparatus. When comes in contact with water, the PPJ affects a change in its physicochemical properties. These changes occur due to the formation of various reactive oxygen-nitrogen species (RONS) in water due to plasma-water interaction. Some of the RONS such as nitrate (NO_3^-), nitrite (NO_2^-), hydrogen peroxide (H_2O_2), and dissolved ozone are successfully identified in PAW.

Brief status in the world and in India:

Properties of PAW and the formation of various reactive species depend on various parameters, such as the type of plasma-forming gas, type of plasma source (e.g., arc discharge, microwave discharge, radio wave discharge, dielectric barrier discharge, etc.), electrode configuration, and tunable operating parameters (e.g., current, voltage, frequency, etc.) of the power source, electrode configuration etc. (2,11-14).

These plasma-liquid interactions generate various reactive species/radicals in water, such as OH, O, O_2, O_2^-, O_3, H_2O_2, N_2, NO, NO_2^-, $ONOO^-$, NO_3^- etc. (14-16), along with high-energy (ultraviolet) radiation and electrons. Presence of these reactive species/radicals in water enables the PAW to be used in aforementioned applications. Figure 2 explains about the mechanism of reactive species formation. Past researchers have reported various configurations of plasma devices, plasma sources, and process parameters such as pin-to-water configuration, cylindrical co-axial dielectric barrier discharge, plasma jet, parallel plate configuration etc. Different plasma sources like non-thermal plasma jet, dielectric barrier discharge plasma/ plasma jet, radio wave/microwave plasma jet, gliding arc discharge etc., have also been studied (2, 9,11-16).

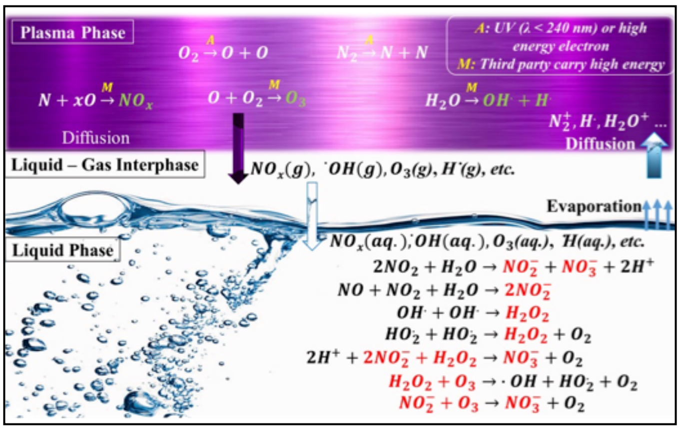

Figure 2: Mechanism of formation of reactive species in PAW

Development of PAW generation System and Process at IPR

The system developed at IPR, uses plasma jet and DBD to produce PAW. Oxygen and nitrogen species formed in plasma interact with water and generate PAW. A System, with a capacity of producing 20 litres per hour of PAW, was developed at IPR for industrial applications (figure 3).

Figure 3: PAW generation system and its control unit

Results

One of our studies shows that the reactivity and electrical conductivity of PAW can be controlled by controlling the process parameters. The obtained results clearly indicate that the flow rate of air, plasma interaction time with water, and plasma discharge power play a significant role in controlling the reactivity and electrical conductivity of PAW [1]. Hence, controlling these parameters has direct impact on applications of PAW. This is due to the fact that high reactive PAW can be used for inhibiting growth of bacteria, fungi, virus, and cancer cells etc. whereas, low reactive PAW has applications in agriculture sector such as improving seeds germination and plant growth etc.

At IPR, we had also explored the bactericidal and fungicidal efficacy of PAW on various pathogenic bacteria and fungi such as *P. aeruginosa, S. aureus, E. coli, E. faecalis, B. subtilis*, and *C. albicans*. Obtained results show that PAW completely inhibited the growth of these pathogens. Moreover, study conducted on bacteria (*P. aeruginosa* and *S. aureus*) reveals that PAW achieves 6+ $\log_{10}$ CFU ml^{-1} reduction even with few seconds (< 10 s) of exposure and retains this bactericidal efficacy for long-term [2]. Results are shown in figure 4. Similar results were also obtained in the fungicidal efficacy of PAW on *C. albicans* but in this case it required higher exposure time (~ 15 min).

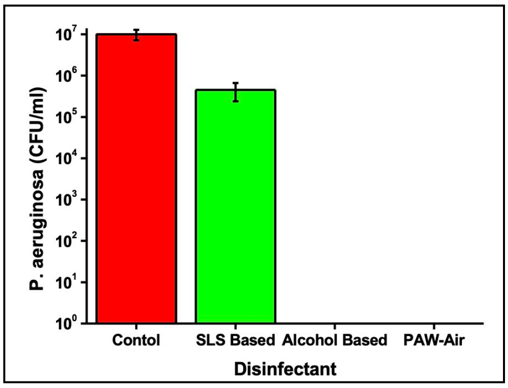

Figure 4: Comparative study of inactivation on *P. aeruginosa*

The morphological analysis and fluorescence microscopy shows that, exposure to PAW has damaged the outer membrane of bacteria and fungi which leads to the leakage of intercellular material thereby making them inactive. Figure 5 and Figure 6 show the change in morphology of cells of bacteria

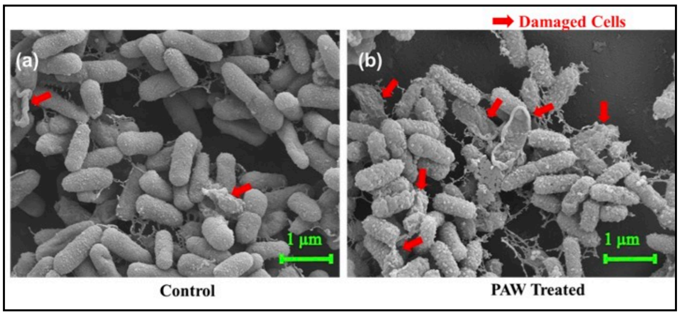

Figure 5: FESEM images showing Morphology of P. aeruginosa cells of (a) control and (b) after treated with PAW

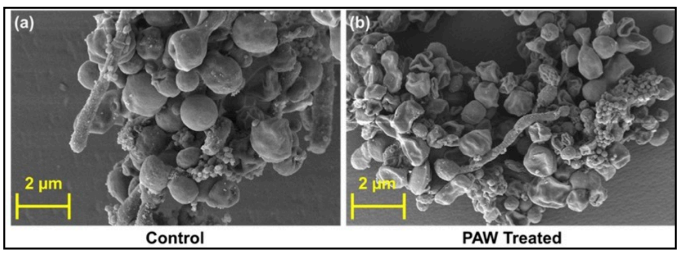

Figure 6: FESEM images showing Morphology of C. albicans cells of (a) control and (b) after treated with PAW

(*P. aeruginosa*) and Fungus (*C. albicans*) after PAW treatment compared to control. PAW treated bacteria and fungi appears shrunk and damaged compared to control.

Our investigation also shows PAW's effectiveness against food fungi. We extracted the *Citrus limon fungi* from lemon's (*Citrus limon*) surface and studied the fungicidal efficacy of PAW on it. Obtained results indicate that PAW completely inhibits the fungi growth (6+ $\log_{10}$ reduction CFU ml^{-1}) with 10 minutes of exposure time and retains this fungicidal efficacy for weeks.

The Potential of PAW in Food Preservation and in Agriculture Field

Due to its strong antimicrobial properties, PAW can be utilized to extend the shelf life of food and prevent spoilage caused by bacteria and fungi. Research at FCIPT, IPR found that washing citrus fruits such as lemon with PAW increased their shelf life by reducing microbial contamination. Over a 60-day study period, the appearance, texture, weight, and sensory attributes of PAW-washed lemons remained intact, while the control group, washed in ultrapure water, showed a significant degradation in these characteristics.

A study was conducted at IPR to investigate the potential of PAW in the field of agriculture by trying to evaluate its effect on seed germination rate. It was focused on to find the effect of PAW on pea seeds' (*Pisum sativum L.*) germination and plant growth. Results showed that PAW treatment significantly improved seed germination and plant growth compared to control. This was attributed to the removal of naturally occurring wax from the seed surface, which improved the wettability properties and facilitated rapid water absorption. As a result, PAW-grown pea plants displayed higher agronomic traits, increased chlorophyll 'a' content, sugar and protein levels, and enhanced antioxidant enzyme activity compared to the control.

Conclusion and future direction

In conclusion, we can say that PAW has the potential to be used as a chemical-free alternative for various disinfection purposes (bacteria, fungi, virus, and pest, etc.). Further, it also has the enormous potential to be used in the healthcare, agriculture, and food sectors. Following points can be concluded:

- It is possible to control pH and ORP of PAW by varying process parameters. Therefore, the PAW can be used for multiple applications.
- PAW has shown bactericidal and fungicidal tendency against *P. aeruginosa* and *C. albicans* which is confirmed using different bactericidal method. Therefore, PAW has potential to replace presently used disinfectants.
- PAW treatment improves the pea seeds germination. In addition, plant length, dry and wet weight, chlorophyll concentration of pea plant also increases significantly compared to control.
- PAW can be used for large number of applications including wound healing, killing of cancerous cells, sterilization of hospital floorings, food preservation etc.
- IPR has demonstrated PAW production @ 20 ltr. per hour for commercial exploitation of PAW in dairy and agriculture sector.
- IPR has transferred the technology know-how to two Indian companies.

Suggested Reading

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Surface Enhanced Raman Scattering (SERS) Substrate for the Detection of Various Molecules

Institute for Plasma Research (IPR) has developed Surface Enhanced Raman Scattering (SERS) substrates for the detection of various complex molecules present in very low concentrations. This development involves the utilization of a patented technology of ion-beam nanostructured glass/silicon substrates with silver nanoparticle arrays grown over them. In this method, molecules under investigation are brought in contact with metal nanoparticles of typically 10-50 nm in size and then standard Raman spectra is collected. Characteristic vibrational modes of the molecules are probed. Normally such modes are undetectable by Raman Spectra, when the molecule concentration is very low. However, in the presence of metal nanoparticles, molecules with the same concentration result in enhanced Raman signals with clearly resolved peaks. In the developed SERS substrates, this condition is achieved by growing arrays of nanoparticles which help enhance electromagnetic field between nanoparticles, due to plasmonic coupling. A molecule present in this region (hot-spot) will experience enhanced field which leads to higher Raman scattering signal. In this way, SERS can be used for the detection of various biomolecules, pesticides, dyes, etc. even at extremely low concentrations. Image of the developed SERS substrate is shown in figure 1, and FESEM image of nanoparticle arrays on patterned Si substrate is shown in figure 2.

The developed SERS substrate has been used for the detection of various biomolecules, pesticides and hazardous dyes used in spices, foods, fruits and vegetables. Initially, the SERS substrate is used for the detection of Glucose molecules from Glucose solutions of different diluted concentrations, and the observed SERS spectra is shown in figure 3. It is clear from the spectra that glucose having concentration as low as $5x10^{-5}$ g/ml, which is much lower than the normal blood glucose level ($\sim10^{-3}$ g/ml), could be detected by using SERS substrate with arrays of silver nanoparticles grown on ion beam patterned Si substrate without using any binder molecule.

Figure 1: Image of IPR SERS Substrate

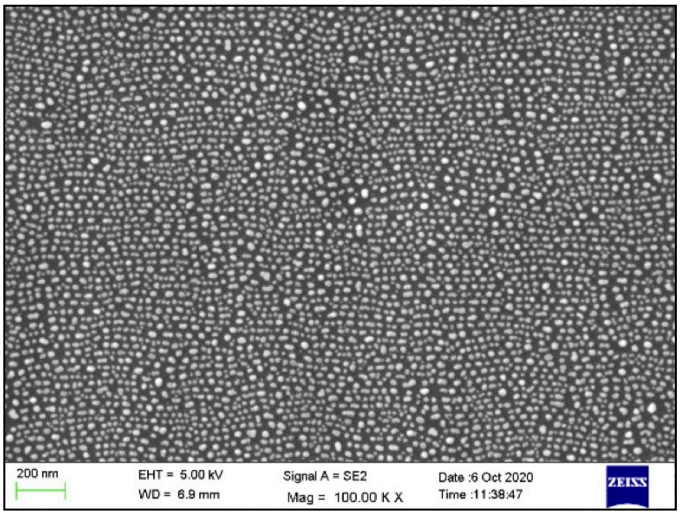

Figure 2: FESEM image of Ag nanoparticle arrays

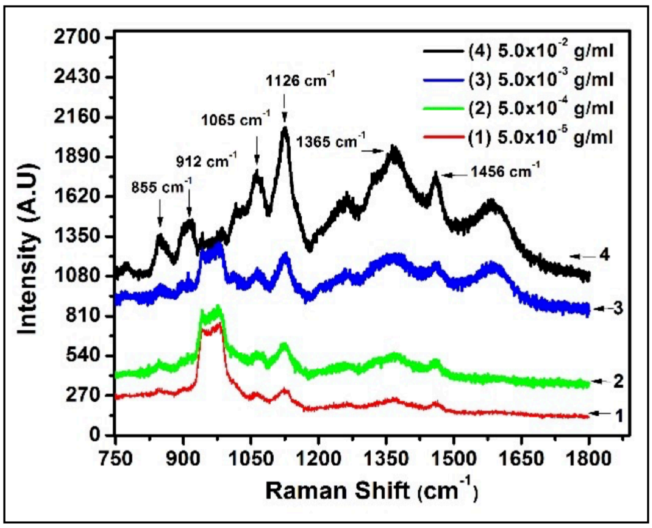

Figure 3: SERS spectra of glucose of different diluted concentrations

The SERS substrate was also used for the detection of Dichlorvos pesticides and various dye molecules (Crystal Violet, Rhodamine B, Erythrosine B, Metanil Yellow, Sudan I, Sudan II, Sudan III, melamine, etc.) at various diluted concentrations. The SERS spectra of Dichlorvos pesticide is shown in figure 4. It is clear from the spectra that Dichlorvos having concentration as low as 1 ppm could be detected using the SERS substrate. Most of the dye molecules mentioned above are used as food adulterants. Rhodamine B and Sudan dyes are adulterants used in chilli powder, Metanil Yellow is used in turmeric powder and Erythrosine B is used in watermelon. Initially, normal Raman and SERS spectra were taken with pure dye samples and the observed limit of detection (LoD) values for each type of molecule are presented in table 1. The SERS spectra of some of the dyes (Rhodamine B and Erythrosine B) are show in figure 5 and 6.

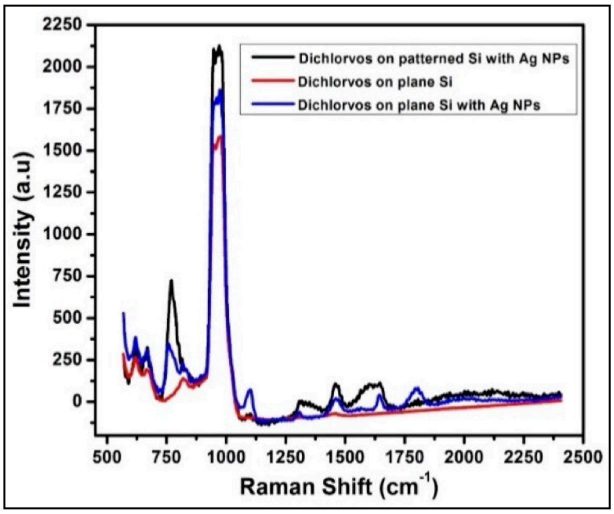

Figure 4: SERS spectra of Dichlorvos pesticide at various diluted concentrations

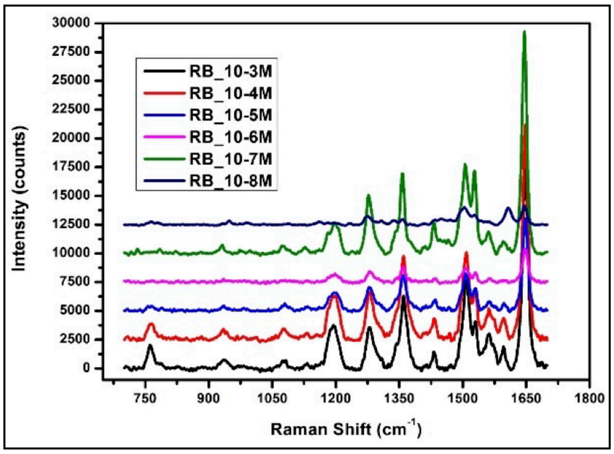

Figure 5: SERS spectra of Rhodamine B

The SERS analysis with glucose, pesticides and various dyes using developed SERS substrates shows its potential to detect complex molecules at extremely low concentrations.

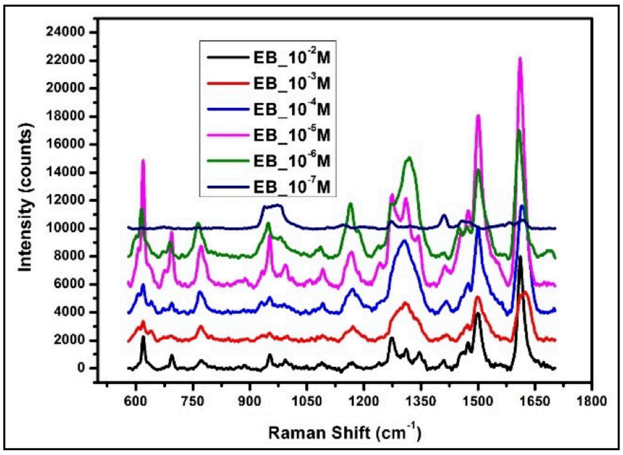

Figure 6: SERS spectra of Erythrosine B

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Leveraging AI Technologies for Healthcare System in India

Introduction

Health is a vital component for maintenance and sustainability across the globe. A nation can thrive only when it's population is healthy. India being the most populous country in the world with diverse region, occupation and climatic conditions, it is a big challenge to have a robust healthcare system. India grapples with shortage of healthcare professionals, as manifested by very low ratios of, for example, available radiologists versus number of patients. This imbalance prolongs the waiting time for diagnoses, thus hindering timely interventions, and worsens health outcomes. Artificial Intelligence (AI) with digital & computational technology can provide a valuable decision-making supporting tools for more efficient screening, detection and diagnosis for pan India. This vision is in line with the aim of transforming India's healthcare to a system which is affordable and accessible not only in Urban but also in rural and semi urban India.

Development of AI based technologies at IPR

With this pan-India vision in mind, Institute for Plasma Research (IPR) is developing various AI based technologies. Following are the AI based tools/technologies developed at IPR, which are extremely useful in healthcare industry.

Deep CXR and SaaS

IPR has developed a deep-learning based AI tool "DeepCXR" for automated screening & detection of pulmonary TB & other lung diseases using Chest X-Ray (CXR) images. A single AI tool that can work for both adults & pediatrics, is a product of collaborative research between IPR, Indian Council of Medical Research (ICMR), Delhi, and 20 other medical colleges/institutions across 10 different states within the country. This AI technology aligns itself with the Government of India's (GoI) Revised Nationwide TB Elimination Program (RNTCP) by identifying footprints of pulmonary tuberculosis/ other chest ailments e.g. mass, nodules, lung cancer in CXR images. DeepCXR has undergone rigorous training, testing and validation. It is trained on a large data set from all four zones (east/west/north/ south), from more than 10 different states, 18 different sites across the country and spanning over more than 50 disease categories. Its performance was evaluated multiple times on large X-rays data sets including survey data of India. The sensitivity/ specificity is > 97 % on the given test datasets from ICMR.

DeepCXR can be used extensively in all hospitals, CHCs & PHCs to fill in the existing gap of patient to medical practitioner ratio. It has been approved by the Department of Health Research (DHR), ICMR, MoHFW (Ministry of health & family Welfare, GoI), for field deployment, endorsing it as a mature technology & suitable for wider adoption in India. It has also been recommended by ICMR to Central TB Division (CTD), MoHFW, to use it to screen larger population of India under NTEP (National TB elimination program of India) program.

IPR has also made operational 'a Software a Service' (SaaS) system i.e. a cloud server based DeepCXR solution for NTEP (medcloud.ipr.res.in), for public through MoHFW, GoI. Using SaaS system, one can interpret a scanned X-ray image and get AI generated report instantaneously within minutes which means that the final report can be generated before the patient leaves the healthcare facility. Currently, it is being utilized by multiple sites from Himachal Pradesh (HP) & Telengana. Further requests from more than 500 sites across 13 Indian states, including Punjab, Chhattisgarh, Madhya Pradesh, Uttar Pradesh, Nagaland, Meghalaya and others are in pipeline.

AI Generated Report of one such CXR image as uploaded by a site from Himachal Pradesh, is shown in Figure 1. Report shows X-ray images with clearly marked abnormal regions, along with findings & impressions.

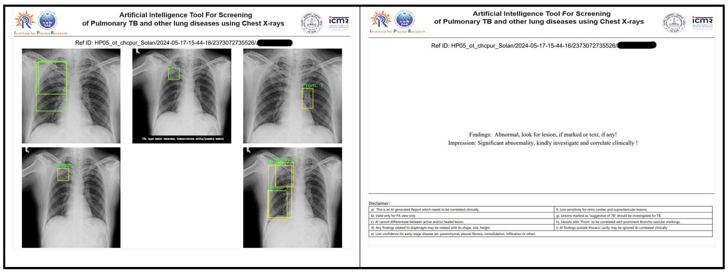

Figure 1: AI generated report

Digitizer Box

Further, IPR has also designed and developed a low cost, easy to use, highly portable chest X-Ray digitizer box for digitizing the data from physical X-Ray films. Photograph of the digitizer box along with the software is shown in figure 2. IPR has supplied this indigenously developed X-Ray film digitizer box to participating institutions for digitizing old X-ray films to be used in training of AI model.

Figure 2: (a) Digitizer box (b) associated software

AIbacilli

At IPR, we have developed a AI based software for fast & auto detection of mycobacillus from smear sputum test, which is a standard clinical diagnosis for detection of mycobacillus. Conventionally, the manual process takes about 10 minutes to analyze the sample specimen (which comprises of ~100 fields) by medical experts. This AI tool helps in reducing the painstaking task of continuously looking into the microscope. The software can detect the number of bacteria in the sample specimen and quantify the bacterial load accordingly. AIbacilli is now integrated with an online microscopic examination system for identification of single/multiple bacilli in the sample specimen from smear sputum test. The system encompasses a robotic feature attached to the microscope which slides the sample and simultaneously alters the magnification level for zooming into the region for clear identification. Concerned picture is shown in figure 3. Indian Patent is sought for this technology.

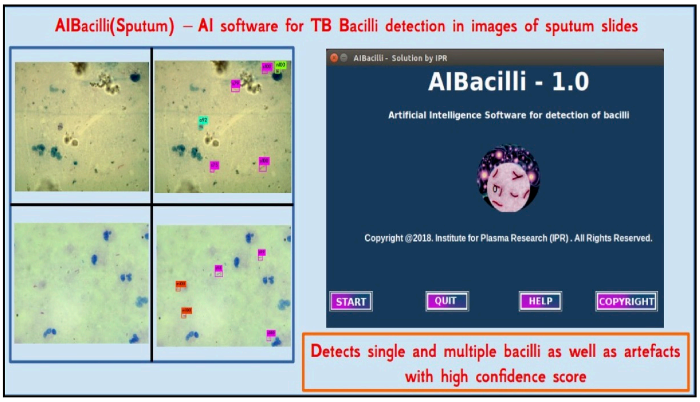

Figure 3: AIbacilli

Generative AI is being implemented to support the in-house ongoing AI projects.

AI for Oncology

IPR, under an MoU with Mahamana Pandit Madan Mohan Malaviya Cancer Centre, Unit of Tata Memorial Center, Varanasi, is developing an 'automated image analysis tool' for deducing the 'scoring of estrogen receptor (ER)' from a provided image. The goal of the project is to calculate the score for ER expression in immunohistochemically (IHC) stained whole-slide images. The scoring system is crucial in breast cancer diagnosis. This scoring can be automated to provide a consistent, objective assessment of ER expression, assisting pathologists in clinical decision-making. The project faces challenges such as accurately identifying individual cells in dense clusters and ensuring consistency in intensity measurement across varying image conditions. Cell counting in dense clusters is shown in figure 4.

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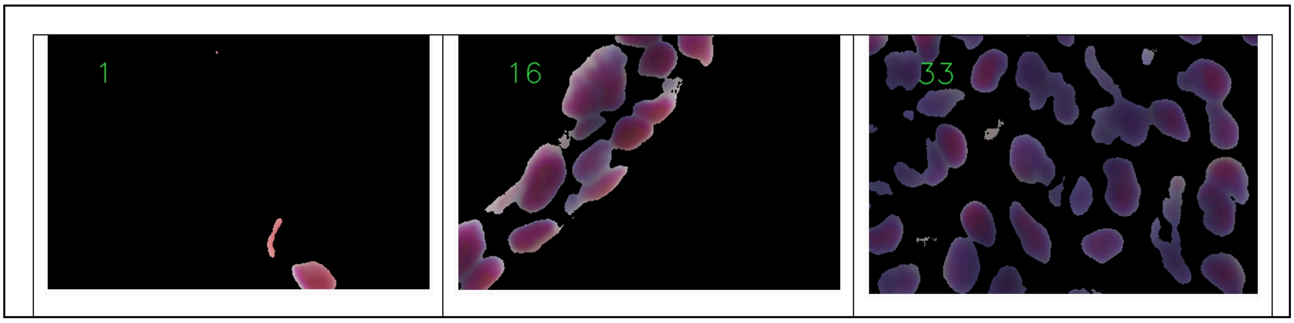

Figure 4: Cell Count in dense clusters

Development of Plasma based Nano-powder Synthesis System

Introduction

Nanoscience and nanotechnology has generated tremendous interest among both researchers as well as technologists due to its potential applications in varied fields as diverse as biomedicine, optoelectronics and metallurgy. Materials when reduced to nanoscale, exhibit properties completely different from their bulk counterparts. Exotic properties of various nanomaterials have been demonstrated at laboratory scale by several groups. These properties have applications in many of the day-to-day used devices. However, it is not so common to come up with products based on nanosized materials as production of nanomaterials on large scale with controlled specifications is quite challenging.

The most common method of nanoparticle production is by wet chemical process. Other methods include PECVD (Plasma Enhanced Chemical Vapour Deposition), Thermal CVD, hydrothermal process, ball milling, laser ablation etc. However, all these processes have the disadvantage of extended time scales of production and involving a number of intermediate steps with impurities creeping in at various steps, low production rates or varied process for varied materials.

Thermal plasma based nanosynthesis is not constrained by the above mentioned drawbacks. This process also provides a method to produce large variation in shapes and sizes of nanoparticles with a possibility to produce size variation of few tens of nanometers. The size and shape variation can be effectively controlled by tuning only the process parameters; whereas in other techniques changes in experimental setup would also be required.

Working Principle

Thermal arc plasma process works on the principle of evaporation of a solid mass to its gaseous state (assisted by the high temperature of the plasma) and then nucleation and growth of the vapour phase to solid in small clusters of atoms/molecules. Depending on the residence time of the vapour in the hot zone, temperature gradient present in the synthesis system, and a few other parameters; the size of the cluster could vary from a few nanometres to few tens of nanometres.

Development of Nanopowder Synthesis System at Institute for Plasma Research (IPR)

At IPR, taking into account the industrial demand for developing a robust, simplified technique for large scale production of various nanopowders, specially metal oxide nanoparticles, an activity on developing thermal plasma based nanopowder synthesis system was initiated with funding from DST under Technology Development and Transfer (TDT) scheme. The system consists of a plasma torch, in which an electric arc is struck between two electrodes viz. cathode and anode. A schematic diagram explaining about thermal plasma nano synthesis is shown in figure 1. A DC constant current (few tens of amperes) source power supply is employed to strike the electric arc. Cathode is generally made out of a refractory material like Tungsten. Typically it is of cylindrical shaped with diameter in the range of 10 – 20 mm, and with

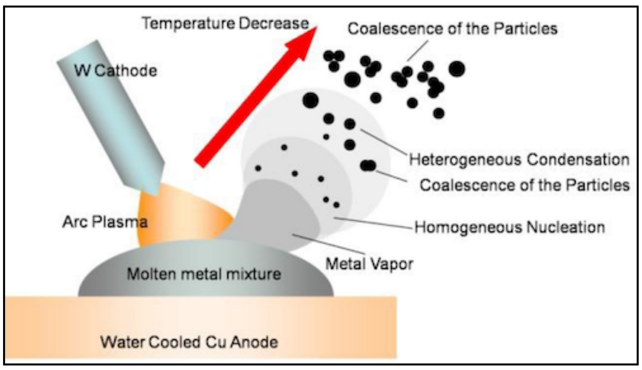

Figure 1: Schematic diagram of thermal plasma nano synthesis process [1]

varied length. And the anode is made out of that material whose nanopowder is to be produced. Materials such as, for example (but not limited to) – zinc metal (in any form - pellets/ powder for production of zinc oxide nanoparticles), titanium metal for titanium dioxide nanoparticles and so on.

The high temperature zone of the electric arc melts and evaporates the anode material such as zinc (or titanium as the case may be). The temperature of the arc zone can be controlled by varying the current applied between the electrodes. The distance between the electrodes is maintained by an automated motor movement with a voltage sensor between the electrodes. The ionised metal vapours move out of the arc zone, in the process becoming neutral atoms as well as reacts with the surrounding ambient (process gas such as air/oxygen etc) to form the metal oxide molecules and then on to clusters of groups of molecules. The atom/molecule cluster size is dictated by the ambient temperature which is kept minimum (at around room temperature). A photograph of the system developed at IPR is shown in figure 2.

Figure 2: Photograph of the Nanopowder synthesis system developed at FCIPT, IPR

Various types of nanomaterials have been synthesised and studied for their properties. They include (i) titanium dioxide (ii) zinc oxide (iii) iron oxide (iv) cobalt oxide (v) silicon carbide (vi) boron nitride etc. Readers may refer to the scientific publications and a book chapter provided under suggested reading [1-7], at the end of this article, detailing the various materials prepared and studied by the developed system. Transmission Electron Microscopy (TEM) images of a few of the produced nanoparticles are shown in figure 3. In the preparation of all these materials, experimental setup remained the same with changes only in the operational parameters and gas ambient. A feeble gas/air draft ensures that the fine particles/metal oxide vapours are carried to an ante-chamber where a novel filteration technique is employed to trap and collect the fine powders. The system is capable to run continuously for hours with no necessity for any human interference. The system will generate nanoparticles as well as collect them in the collection chamber.

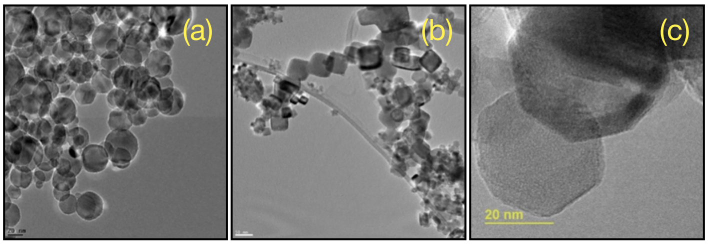

Figure 3: TEM images of (a) Titanium oxide (b) Cobalt oxide (c) iron oxide nanoparticles produced at IPR

Patent & Technology Transfer

An Indian patent with Patent No. 467608 on the above process (A system and method for preparation of the metal oxide nanoparticles) was granted in November 2023 for a period of 20 years.

The technology is also transferred to the following four Indian industries:

i) Plasma & Vacuum Technologies, Ahmedabad
ii) Vishal Engineers & Galvanizers Pvt Ltd., Ahmedabad
iii) Rubamin, Vadodara
iv) FCG HiTech Pvt Ltd., Vapi

All the above Industries have taken the technology mostly for zinc oxide production.

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This section highlights those plasma based technologies that have been tested in a simulated or relevant environment. The performance of these systems is assessed and they found to deliver promising results. Potential challenges associated with these technologies could be identified and more efforts to make them useable for societal applications are underway. For more specific and complete details, please contact ptts@ipr.res.in.

Plasma Assisted Physical Vapour Deposition using Magnetron Sputtering

Introduction

Physical Vapor Deposition (PVD) is a widely used thin-film deposition technique that involves physical transformation of materials into vapour and their subsequent condensation onto a substrate to form a solid film. It is known for producing high-quality coatings with superior properties. There are several ways in which PVD coatings can be produced. Plasma-Assisted Physical Vapor Deposition (PAPVD) is a class of PVD techniques, in which plasma characteristics are used for enhancing the quality and properties of conventional PVD coatings. Salient features of the PAPVD technique are:

- Produces dense coatings
- Coatings with few macroscopic defects
- Coatings with very good adhesion to the substrates
- Environmental friendly technique
- Ease of sputtering any metal, alloy or compound
- Ability to coat Heat sensitive Substrates

Development of PAPVD systems at Institute for Plasma Research (IPR)

IPR has developed magnetron based PAPVD systems which can deposit coatings of various materials viz. metals (Cu, Al, Zn, Ti, Cr, Ag, Mo etc.), compounds (TiN, AlN, ZnO) etc. on different types of objects. Systems with different magnetron geometries like circular, rectangular, cylindrical are developed. Some of the coatings developed, developed at IPR, for important medical applications are discussed below.

A. Development of TiN coatings for HIP implant Applications

Stainless steel 316L (SS 316L) is commonly used as an implant material due to its favourable combination of mechanical properties, corrosion resistance, satisfactory biocompatibility and cost effectiveness compared with other metallic biomaterials. It is used for the fabrication of typical internal fixation devices such as artificial joints, bone plates, stents etc. However, SS 316L and other austenitic stainless steel types (such as SS304, SS310) are rather soft materials and often suffer from a high amount of wear caused by mechanical loads. Hardness and wear resistance of these SS 316L alloys can be improved by applying an appropriate surface modification technique. Deposition of TiN coatings using PVD technique is a most popular method for enhancing mechanical properties on the surface of SS316L components. At IPR, a PAPVD based process was developed which was optimized for depositing multi-layered Ti-TiN coating on SS 316L substrates. A planar-magnetron configuration was developed for depositing the desired coatings, and pure Titanium (Ti) disks were used as target material. Figure 1 shows pictures of in-progress deposition process, and coated &

uncoated *Hip implant femure head*. For obtaining uniform coating on this spherical femure head, a substrate rotating mechanism was also designed & developed. This work was carried out in collaboration with CGCRI, Kolkata, with funding form Department of Science and Technology (DST).

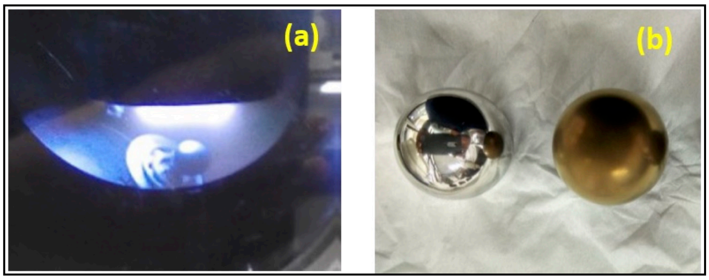

Figure 1: (a) Hip implant femure head being coated (b) Uncoated and TiN coated femure heads

B. *Antimicrobial CuO coating on fabric/ yarn using cylindrical magnetron sputtering*

Medical textiles are specialized fabrics designed for healthcare and clinical applications. They play an important role in various medical settings due to their unique properties, which enhance patient care and safety. Controlling the growth of bacteria on these textile surfaces is very crucial. Copper oxide (CuO) has gained significant attention for its antibacterial properties, making it a promising material in various applications including the area of medical textiles. A PAPVD based cylindrical magnetron sputtering process was developed at IPR, for depositing CuO coatings on polyester yarn. A mechanism was also designed & developed for a continuous deposition of 50-100 nm thick CuO coating, on a moving polyester yarn in low pressure conditions. In this mechanism, speed of the yarn movement can be controlled. The deposited CuO coating was tested for its composition, morphology and antibacterial efficacy. Antibacterial tests conducted on coated yarn have shown no growth of bacteria (Staphylococcus Aureus and Escherichia Coli). These coated yarn can be used in bandages, wound dressing material etc. for reducing bacterial infection from atmosphere. Figure 2 shows schematic of the process as well as picture of the CuO coated and uncoated yarn.

Conclusion

A plasma based physical vapour deposition technique offers many advantages over other techniques. Over the years, IPR has developed different coatings as well as plasma based systems for deposition of such coatings. Lab-scale magnetron sputtering systems were also supplied to four different institutes in India. IPR also takes up feasibility study projects for developing specific and/or complex coatings & systems for industry, research institutes etc. in India.

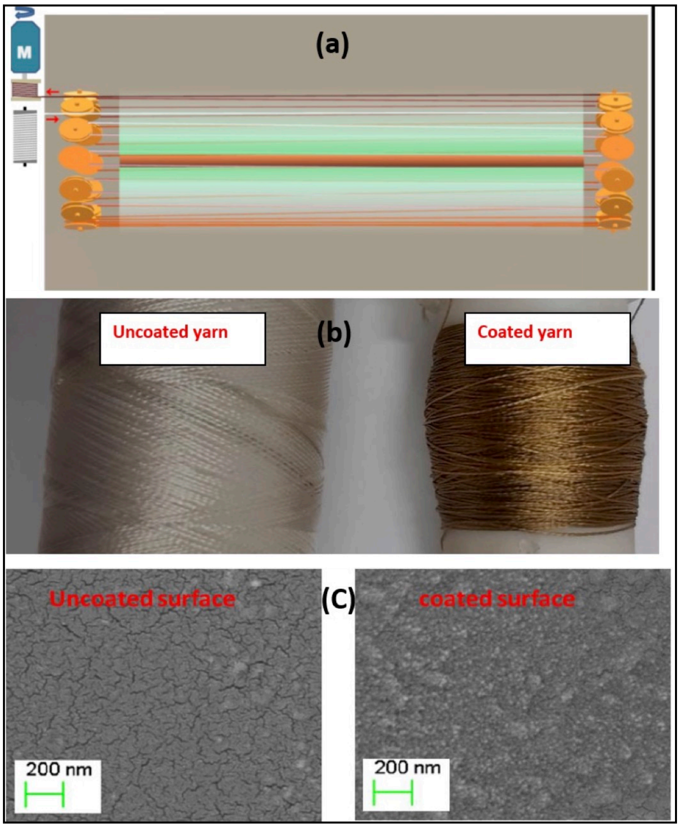

Figure 2: (a) Schematic diagram showing coating process (b) Uncoated and Coated yarn and (c) SEM images of uncoated and coated surfaces

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Cold Plasma Technologies for Sterilization of Medical Equipment

Introduction

Sterilization by definition means complete annihilation of all forms of life. Conventionally it is achieved by methods which employ dry/wet steam, exposure to Ethylene Oxide or Peroxide vapours, treatment via germicidal ultraviolet radiation. These methods have inherent limitations such as exposure to high temperatures, toxic chemicals, non-uniform treatment etc.

Plasma sterilization technology is an innovative method that utilizes plasma for eliminating microorganisms, including bacteria, viruses, and fungi, from various surfaces and materials. This technique can affectively overcome many of the aforementioned limitations of conventional technologies and offers superior sterilization capabilities. The device uses low pressure cold plasma which is rich in reactive species such as hydroxyl radical (OH); O* (excited oxygen atom), O_2* (excited oxygen molecule), O^+ (ionized oxygen atom), O_2^+ (ionized oxygen molecule), O_3 (ozone); reactive nitrogen species (RNS) like N* (excited Nitrogen atom), N^+ (ionized nitrogen atom), N_2^+ ionized nitrogen molecule etc. These species result in etching of outer cell membrane of microorganism and denature of proteins responsible for life sustaining activities of a microorganism.

Plasma Sterilization work at Institute for Plasma Research (IPR)

At IPR, we have been working on developing Plasma Sterilization technology for sterilizing medical equipment. Application for an Indian patent is also filed by IPR (application number: 202421018111). Figure 1 shows the chronological evolution of Plasma Sterilization technology developed at IPR.

Over a period of time, IPR established close academic collaborations with several organizations such as B. V. Patel Pharmaceutical Education and Research Development (PERD), Ahmedabad; Central University of Gujarat (CUG), Gandhinagar.

IPR further collaborated with several institutes such as Central Instrumentation Facility of Indian Institute of Technology (IIT) Gandhinagar, National Forensic Science University (NFSU), National

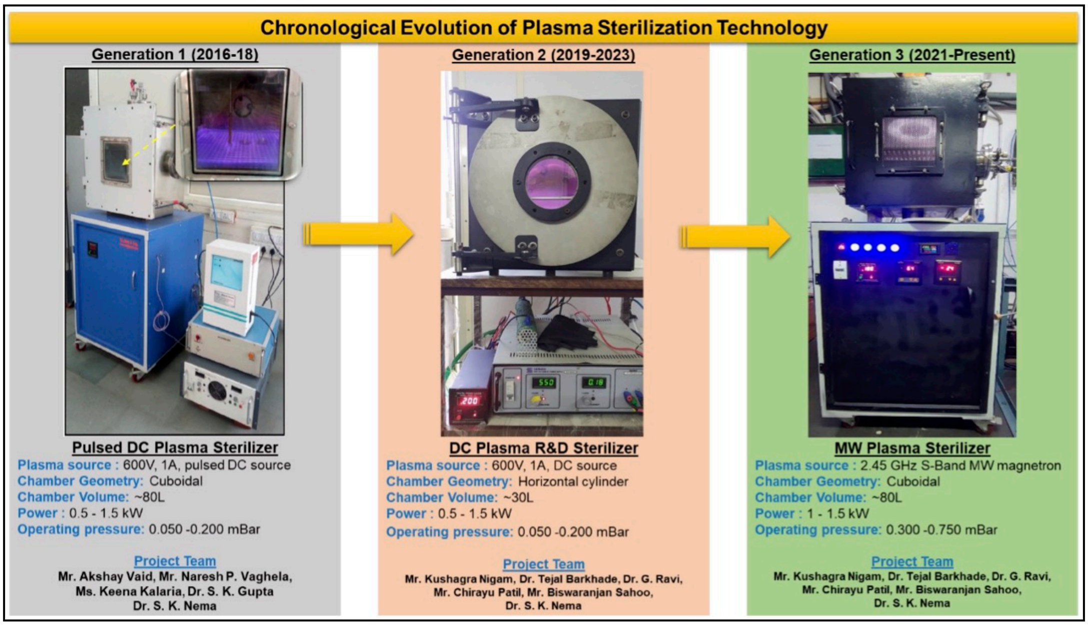

Figure 1: Chronological evolution of Sterilisation Technology at IPR

Institute of Pharmaceutical Education and Research (NIPER), Gujarat Biotechnology Research Centre (GBRC) and M/s Biocare Research, Ahmedabad, for utilizing their facilities for necessary characterization requirements. These collaborations enabled us to conduct detailed research studies on effect of plasma on microbial species both at cellular and genetic levels. The characterization facilities provided us state of the art instruments to conduct investigations at microscopic scales.

Trials on Bacterial Species

Colony forming unit (CFU) reduction trials have been undertaken on gram positive and gram negative bacterial species. A CFU is defined as a unit consisting of a viable number of microbial cells that can multiply via binary fission to form multiple colonies. CFU analysis is used for quantifying the viable bacteria cells before and after the plasma treatment, thus giving a direct measure of killing efficiency of the sterilization process. Figure 2 and figure 3 show qualitative analysis and 'quantitative graphical representation' of CFU reduction in gram-positive *Staphylococcus aureus (SA)* and gram-negative *Salmonella abony (SAb)* bacteria samples. The bacteria samples were exposed to plasma, inside the sterilization chamber, for different time duration (1-10 minutes). Figure 2 shows a significant CFU reduction as evident from decrease in number of dots in petri plates. Figure 3 shows the logarithmic reduction curves (Log (CFU/mL) with respect to exposure time (minutes).

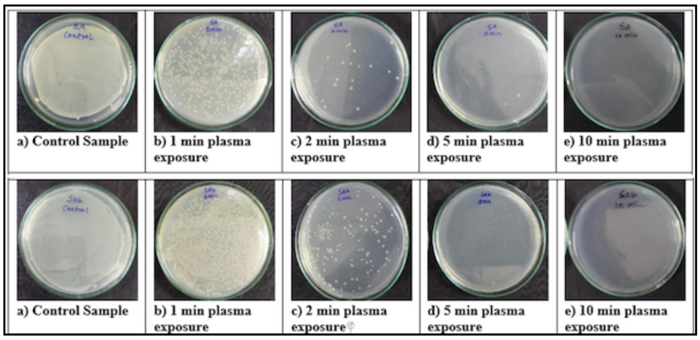

Figure 2: Petridish cultures used for evaluating CFU count in SA (top series) and SAb (bottom series) bacterial samples

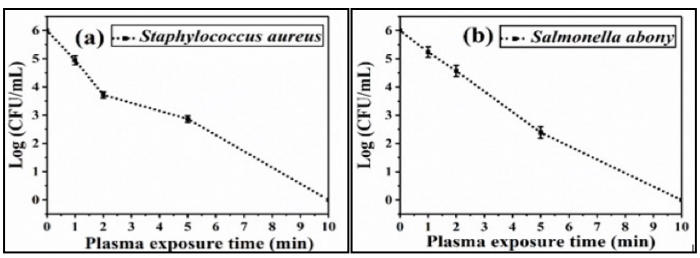

Figure 3: Graphical representation of CFU reduction with Plasma exposure time

Trials on Surgical Instruments

Another study was conducted to mimic hospital like conditions wherein multiple metallic as well as non-metallic surgical instruments were required to be simultaneously sterilized. A collection of metallic and non-metallic surgical equipment was loaded with *Staphylococcus aureus (SA)* bacteria. The bacteria loaded equipment are then sealed in Tyvek packets (figure 4). The sealed equipment are kept inside sterilization chamber in two separate stacks (figure 5 a) and are then exposed to plasma for 15 minutes (figure 5 b). The bacteria samples are then collected from the surface of treated equipment and analysed. The results are then compared against those from a control sample which did not undergo plasma exposure. Figure 6 shows the nutrient agar

Figure 4: Tyvek sealed surgical equipment loaded with *Staphylococcus aureus (SA)* bacteria

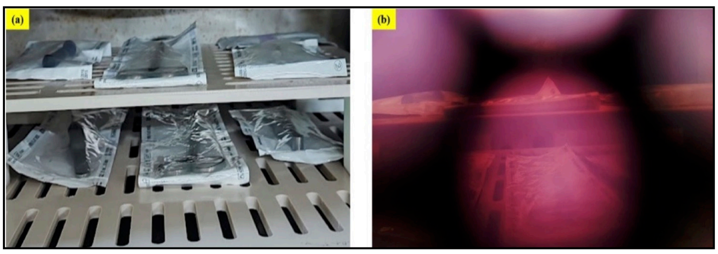

Figure 5: (a) Tyvek sealed surgical equipment inside sterilization chamber (b) equipment getting exposed to plasma

plates of different plasma treated metallic and non-metallic equipment against control sample. The syringe plunger, forceps and scissors showed significant viable colony reduction. No growth was observed in the syringe barrel, towel clip and syringe needle. The test demonstrated the treatment efficacy of plasma sterilization device on both metallic and non-metallic surgical instruments.

Conclusion

The plasma sterilization device designed and developed by IPR holds immense potential for commercialization across various sectors. The technology uses locally available resources and aligns with *Make in India* and *Atmanirbhar Bharat* initiatives of Government of India.

We are always looking for collaborations with different public and private industries for commercialization and product development. The potential industries that can directly get benefitted by our technology include hospitals and private clinics, microbiology research labs, mobile clinics, pathologies, dental clinics etc.

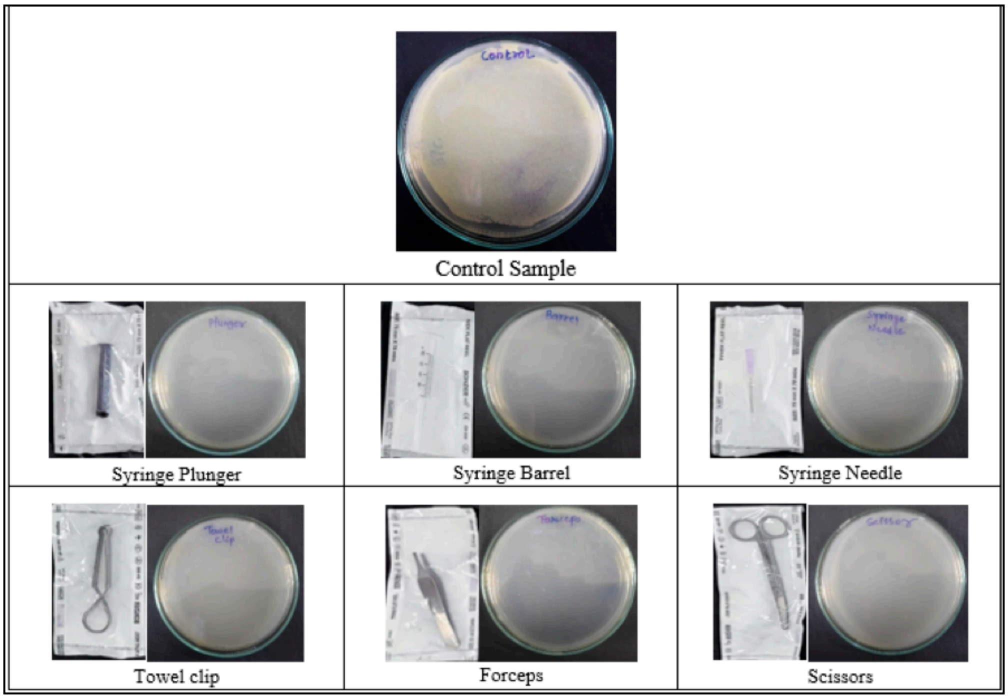

Figure 6: N Agar plates of *Staphylococcus aureus (SA)* bacteria revived from plasma treated surgical equipment

Atmospheric Pressure Plasma Jet for Bio-medical Applications

Introduction

In recent years, cold non-thermal atmospheric pressure plasmas have found tremendous applications in bio-medical fields. Atmospheric pressure plasma jet (APPJ) is a non-thermal plasma device that can be used in various bio-medical applications. Plasma is produced in these devices based on Dielectric Barrier Discharge (DBD) principles, in which dielectric material such as quartz and alumina cover one or both electrodes, and by applying high voltage between live and ground electrodes, discharge is ignited. The plasma so formed can be touched with bare hands. Helium and argon are mainly used as plasma producing gases in APPJ.

The plasma jet induces chemical specific response or modification in the biological matter that leads to desired effect

At Institute for Plasma Research (IPR), with necessary collaborations, we have been using APPJs in the following applications:

1. Faster rate of coagulation of blood
2. Treating Skin diseases.
3. Sterilization
4. Apoptosis of cancerous cells.

1. *Faster rate of blood coagulation*

APPJ is tested for increasing the rate of coagulation of blood. It is observed that blood takes about 200 seconds to coagulate naturally, but it is found that when exposed to argon plasma, it can be coagulated within 15 to 20 seconds. Figure 1 shows the comparison of blood coagulation time vs coagulation mechanism.

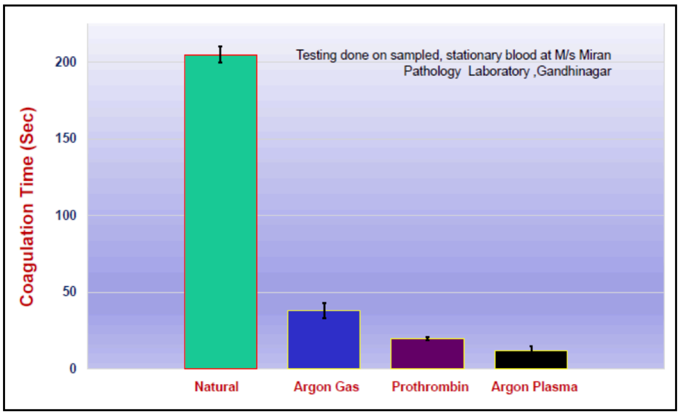

Figure 1: Coagulation time Vs Coagulation Mechanism

2. *Treating skin diseases*

After taking necessary ethical permissions, APPJ is applied to patients affected with Tinea Cruris. After subsequent treatments with APPJ, it is observed that the affected skin has recovered from infection without the administration of antifungal medicines. Figure 2 shows the infected skin, both before and after treatment.

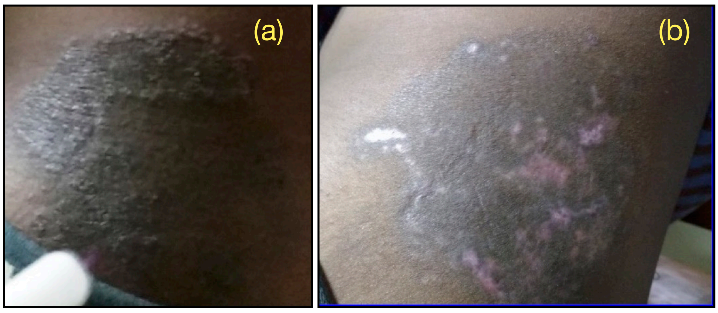

Figure 2: Tinea Cruris infection (a) before and (b) after treatment

3. *Sterilization*

APPJ is tested for its effectiveness on sterilization of pathogens like S. Aureus and P. Aeruginosa, and it is observed that plasma treatment completely disintegrates the cell membrane of these pathogens as shown in figure 3.

4. *Apoptosis of Cancerous Cells*

APPJ is tested for its efficacy against some cancers such as ITOC cell lines (in collaboration with ACTREC, TMC, Mumbai); Glioma (in collaboration

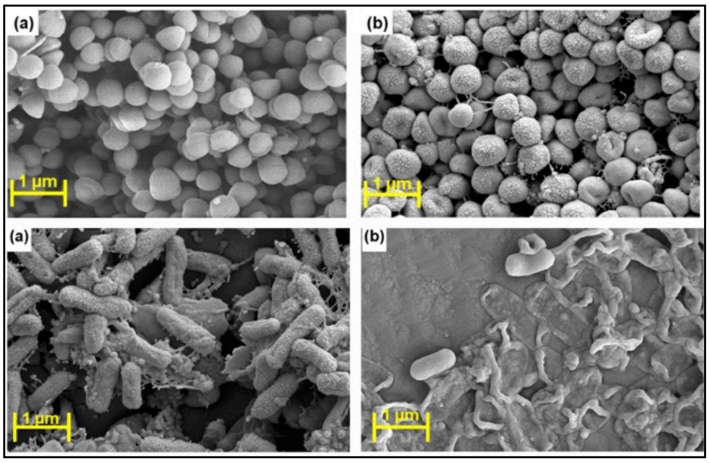

Figure 3: Before and after plasma treatment. a) S. Aureus b) P. Aeruginosa

with AIIMS, New Delhi); A549 cell lines (BARC, Mumbai). It is observed that, after plasma treatment, cell viability of 20 % is found. At ACTREC, animal trials were also conducted on Hamsters, and it is noticed that the tumor volume goes down after subsequent treatments with APPJ. Figure 4 shows a decrease in tumor volume, starting from day one to day eleven, for a treatment time of only 5 minutes each day with APPJ.

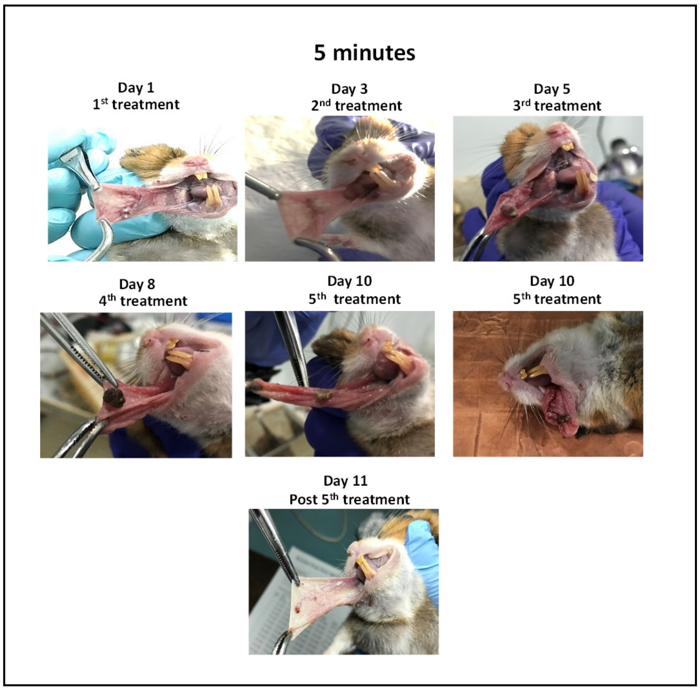

Figure 4: Tumor volume from day 1 to day 11 after 5 minutes plasma treatment, each day

Conclusion

APPJ has been used in plenty of biological applications specially in the area of cancer treatment. Astonishing results are achieved while working on ITOC-03, A549 cell lines and gliomas. This technology is yet to prove its effectiveness. Also, in case of skin treatment, more data needs to be generated so that the APPj can reach to general public. Many more applications such as dental, wound healing also need to be explored in future.

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Plasma Treatment for Enhancing Seed Germination

Introduction

Seed germination is the process through which a seed develops into a new plant. It is an important phase in the plant life cycle, marking a transition from dormancy to active growth. Successful germination is the key for establishing healthy plants and to effect crop yields. Understanding and optimizing the conditions for seed germination is essential in agriculture. Any technique that can enhance the germination process can lead to increased crop yields and ensures food security. Several techniques like seed priming, scarification, thermal and chemical treatments etc. are employed for improving germination rates. Plasma treatment is the new addition to the list.

Work on seed processing at Institute for Plasma Research (IPR)

Plasma based technologies are widely being explored in agricultural applications in general, because of their unique advantages. Seed treatment is one of the areas in which the role of plasma-processing is being studied. Plasma treatment enhances seed germination rates, their decontamination, and also helps in degrading the pesticide residue that was left over them. At IPR, we have been working on developing a plasma based treatment system to process different types of seeds for improving their germination rate. Some of the seeds selected are typically difficult to be germinated. To start with, a low pressure plasma treatment system was used for treating the seeds as a part of feasibility studies. Later, an 'Atmospheric pressure plasma treatment system' was designed & developed at IPR for treating seeds in large quantities. Details of both the processes are presented below.

1. Low pressure plasma treatment system

The parallel plate electrode arrangement was used for generating a plasma and seeds were placed on the lower electrode. A RF (radio frequency) generator was used for generating plasma. The operating pressure was maintained in the range of 0.1 to 0.2 mbar using oxygen gas, and 100 watt RF power was used for seed treatment. Duration of plasma treatment was varied up to 15 minute. The low pressure oxygen plasma treatment on capsicum and Okra seeds showed 20-30 % improvement in germination percentage. The oxygen plasma treatment is observed to increase the surface area of seeds, and the probable reason is plasma's etching effect. Further, it is also observed that surfaces of the seeds also get oxidised. Hence, after plasma treatment the surface of the seeds become more hydrophilic in nature. Figure 1 shows the electrode arrangement, seedling vigor index after plasma treatment and the contact angle before and after plasma treatment. Results indicate that the treatment helps in increasing the germination rate of the seeds. However, this treatment was a batch process, time consuming, and the quantity of seeds that could be treated per unit time was very low. Therefore, there was a need for developing an atmospheric pressure plasma treatment system.

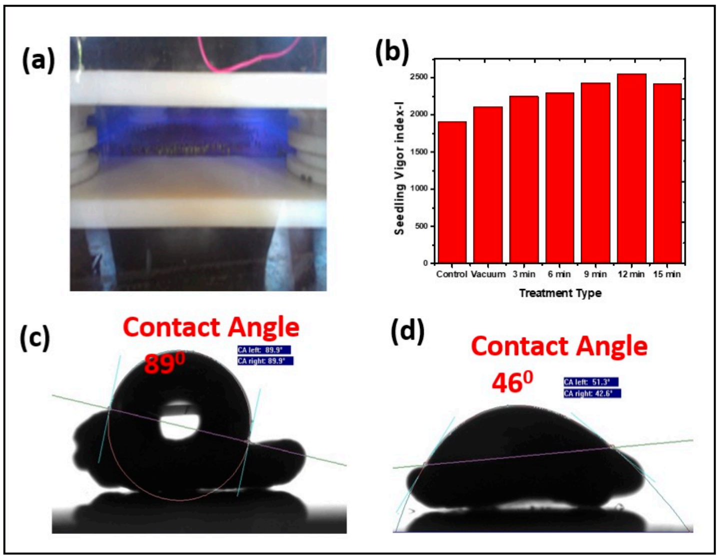

Figure 1: (a) Low pressure oxygen plasma treatment (b) Seedling vigor index for untreated and plasma treated seeds (c) water contact angle for untreated capsicum seed (d) water contact angle for plasma treated capsicum seed

2. *Development of large area atmospheric pressure air plasma system*

The most common plasma source used for seed treatment at atmospheric pressure, is based on planar dielectric barrier discharge (DBD). In order to treat higher quantity of seeds, a large area atmospheric pressure plasma source is developed by using surface DBD plasma. Figure 2a shows a photograph of this system. In this system, multiple DBD electrodes are arranged in series such that, just beneath this series there is an effective plasma treatment area of 800mm x 800mm. The seeds can be spread on a plate of dimension 800mm x 800mm and was placed just below the series of DBD electrodes. Figure 2b shows a portion of the air plasma generated along with the seeds. At present, experiments are in progress for plasma treating the seeds of tomato, capsicum and okra in the system. As shown in figure 2c, germination percentage of plasma treated tomato seeds is increased by 30 %. Further, experiments are in progress to study the effect of plasma treatment on reduction of pesticide residue on cumin seeds. The testing of the plasma treated seeds is being carried out at Dr. Y S Parmar University, of Horticulture and Forestry, Solan, Himachal Pradesh.

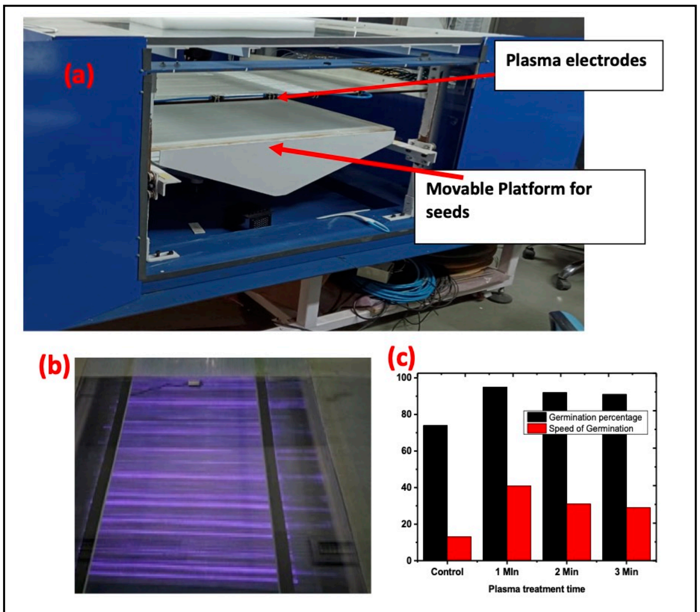

Figure 2: (a) Setup of Large area plasma treatment system (b) Atmospheric pressure air plasma using Surface DBD (c) Germination percentage and speed of germination for untreated and plasma treated Tomato seeds

Conclusion

Plasma processing of seeds for improving germination percentage as well as improving crop/ fruit yield is a promising technology. A good amount of research is required in this field on getting these plasma treated seeds in the marketplace on a grand scale. IPR has started collaboration with relevant agriculture universities to work further in this area.

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In this section, a few plasma based experiments carried out under specific space simulated conditions are presented. Developed facilities simulate the vacuum of space to test arcing phenomenon, material erosion etc. For more specific and complete details, please contact ptts@ipr.res.in.

SPIX

An ISO facility for the Testing of Satellite Solar Panels "Spacecraft Plasma Interaction eXperiments (SPIX)"

Introduction

The recent trend towards placing more transponders in a single satellite has led to increased power requirements for Geosynchronous Earth Orbit (GEO) satellites. To fulfil this increased power need, the satellite bus voltage has to be increased beyond the present value of 42 volts. Typically for a 10 kW coupon the required bus voltage is about 100V. This power level is likely to grow further upwards, which further requires higher bus voltage designs. Increased satellite bus voltage leads to arcing on solar arrays, which is a serious threat to the spacecraft. The problem is compounded by the fact that many of the mitigation techniques like grouting which work in the beginning of life tend to become questionable at the end of life conditions. A further complexity is brought about by the introduction of newer cells and cover glasses by manufacturers. Therefore there is a need to test the performance of these solar arrays at ground conditions. Considering these factors it had become necessary to carry out these tests under the newly developed standards by ISO which is accepted by worldwide federation of national standard agencies including NASA, ESA (ONERA), JAXA (KIT) and others.

Work carried out at Institute for Plasma Research (IPR)

Considering long term goal of Indian space program, (IPR) has developed an indigenous ground test facility "SPIX" to simulate space like conditions in the laboratory. SPIX test facility is capable to experimentally simulate the charging processes of a solar array insulator in LEO (Low Earth Orbit) and GEO orbit. Objective of this activity is to conduct experiments to gain a better physical understanding of Electrostatic discharge (ESD) phenomena on solar arrays. It is expected that the outcome of this experiment will be helpful in preparing guidelines to choose solar array material, configuration and electrical design of solar arrays.

Figure 1: ISO test facility developed at IPR

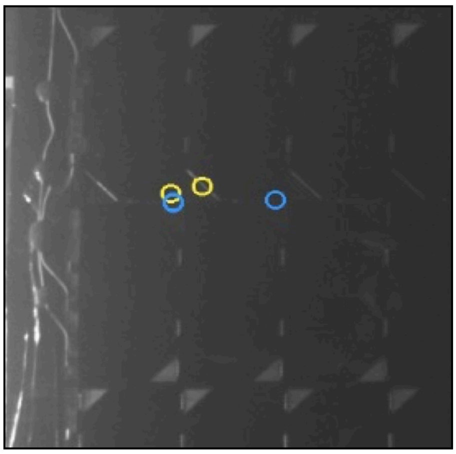

Figure 2: Image showing locations of all arcs observed

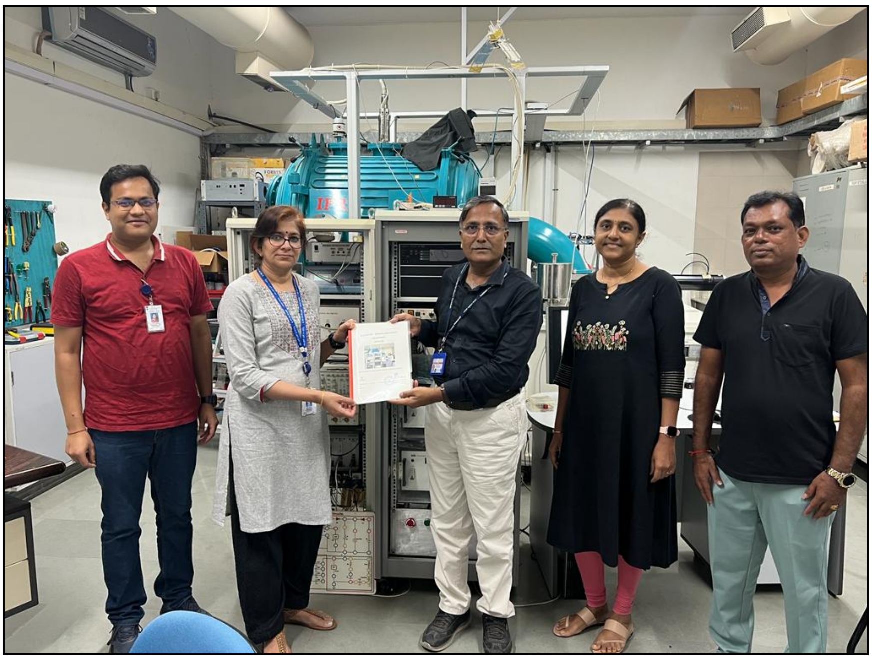

Figure 3: Final acceptance of the ISO test facility "SPIX" by the URSC officials

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Anode Liner Material Erosion Studies for the Development of Hall Effect Plasma Thrusters for LPSC, VSSC/ISRO

Hall Effect Plasma Thrusters (HEPT) are under investigation as a technology aiming to achieve thrust with high exhaust velocities in satellites. In HEPTs, plasma is formed in a narrow annular channel and interacts with inner ceramic wall. Ejected ions from plasma, can erode the ceramic at the edge of the ejection point. The eroded material may eventually deposit on the crucial parts of the satellite and degrade their efficiency, and the parts that are most prone to this are solar cells. Erosion can also expose the underlying magnetic yoke, causing the magnetic field profile to be altered and change HEPT functionality. Therefore, investigation of thruster anode liner erosion and choice of material is very important for its long and stable operation in satellites. Under the development of Electrical propulsion program, ISRO Scientists from LPSC and VSSC have also faced similar issues and wanted a complete plasma understanding, plasma diagnostics and ceramic wall erosion study.

To investigate this important issue of ceramic wall erosion for the indigenous development of Hall Effect Thrusters for Indian Satellites, IPR has developed a Plasma Ion Source facility equipped with in-situ diagnostics probes to monitor the erosion behaviour, trajectories of the eroded material from ceramic material to be used as a anode liner material. After several calibration experiments, scientists at IPR have successfully produced equivalent ion energies and flux comparable to those in plasma thrusters, and performed ion irradiation experiments on ceramic samples for various ion energies of 50 eV to 600 eV for multiple angle of incidents as per the real plasma and exiting ion scenario in thrusters. Later a simulation code was also written for calculating the volumetric and total sputtering yield of the material eroded and gave the feedback to VSSC and LPSC for the material performance. The obtained experimental results were validated with theories and reported results by NASA and other space agencies data [1,2].

It was found experimentally, for all ion energies from 150-550 eV at normal incidence, that volumetric sputtering yield profile remains symmetric with respect to surface normal of the sample (figure 1(a)). This essentially means that sputtered material will eject isotropically along all the directions. At oblique incidence, more material is ejected in the forward direction than in the backward direction and an asymmetric volumetric yield profile was obtained for all the ion energies of 150-550 eV. However, in the lower energy regime, i.e. below 350 eV, back side material ejection reduces substantially. These shape profiles shown in figure 1(a), were compared with Sigmund-Zhang model and obtained a fairly good matching. This model requires the values of ion energy, angle of incidence and generates the shape profile of the volumetric sputtering yield. figure 1 (b) shows the variation of sputtering yield with angle of incidence for two different ion energies viz. 450 eV and 550 eV. This profile was validated by Yamamura model, and this model also predicts a sudden rise in sputtering yield at an ion incidence angle of 55^{o}. Experimentally it was found that ceramic material Boron Nitride (BN) sputtering yield drastically increases in the angle of incidence ranging between 45^{o} to 65^{o} for all ion energies (figure 1(c)) and Yield behaves according to Yamamura model (figure 1(b)). Similar trend of yield was obtained for another candidate ceramic material $BNSiO_2$, which is also used in plasma thrusters. For both the materials a sudden rise in the sputtering yield at ion energy of above 500 eV (figure 1(d)) was observed. Ion energy plays a crucial role in defining the value of sputtering yield. Initially, up to 250 eV the sputtering yield remains

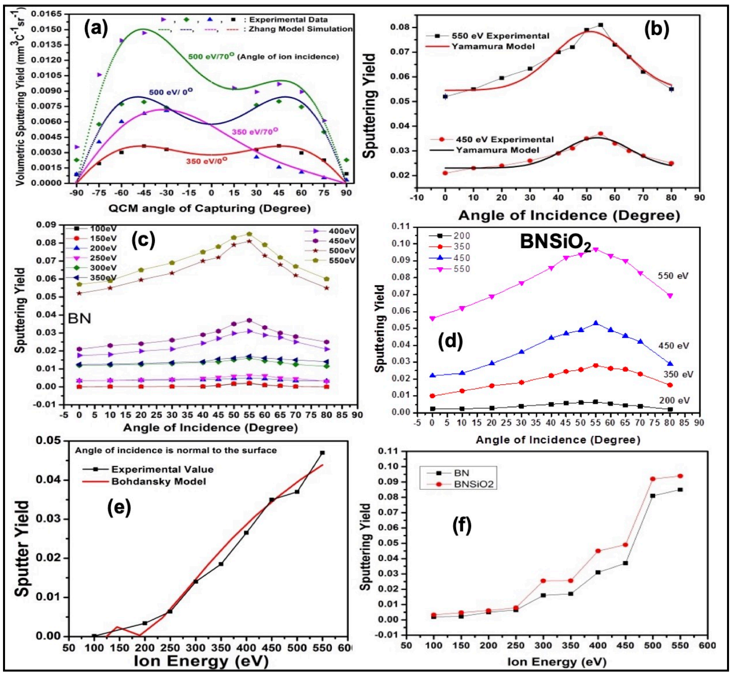

Figure 1: (a)Volumetric sputtering yield variation of Boron Nitride at 0° and 70° angle of incidence irradiated with 350 eV and 500 eV ions. Experimental curve compared with the Sigmund-Zhang model. This exercise was performed for all sets of energies and angle of incidence. (b) Sputtering Yield (SY) variation with angle of ion incidence at 450 eV and 550 eV. Experimental values are compared with Yamamura Model (c) Boron Nitride SY values measured for various ion energies and angle of incidence.(d)Boron Nitride Silicate ($BNSiO_2$) sputtering Yield values for various ion energy and angle of incidence (e) Boron Nitride SY variation with ion energy at Normal incidence and compared with Bohdansky Model . (f) Comparison of SY of BN and $BNSi0_2$ at 55°.

stable and then shoots up for higher energies (figure 1(e)). These energy plots were also compared with Bohdansky model. Finally figure 1(f)) compares the sputtering yield of BN and $BNSiO_2$, the later one is found to have slightly higher sputtering yield.

Obtained results were some of the crucial results as 17 mN thrusters are normally operated in these ion energy ranges. It was planned to operate the thruster at 500 eV ion energy to improve the thrust efficiency, and experimental results show a sharp rise in yield at this ion energy, so operating energy of the thruster was altered accordingly. Just at the thruster exit point, angle of ion interaction with ceramic liner may become in the range of 50° and may lead to faster erosion after long operation. Therefore, different designs are under development to avoid such a scenario. In Plasma thruster, during firing, substrate temperature may also rise to 600°C. So the developed facility was further upgraded to perform high temperature experiments and it was observed that sputtering yield of the material scaled linearly with the temperature. After several iterative experiments, developed ceramic materials were optimised for the least erosion rate comparable to NASA and other space agencies and the ceramic material was qualified for the use in plasma thrusters for Indian Satellites. These findings were highly appreciated by VSSC, LPSC and were also presented to Chairman, ISRO. With joint efforts the

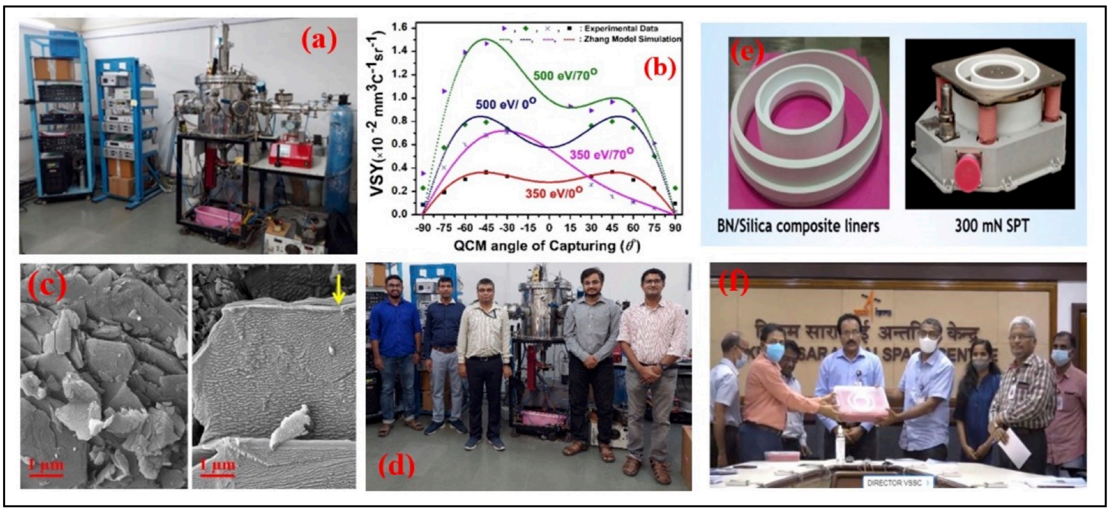

Figure 2: (a) Low Energy Ion Beam Facility, (b) Volumetric Sputtering Yield (VSY) profiles, (c) SEM images of sample before and after irradiation and variations in erosion rate with temperature, (d) team members, (e) Machined Anode Liner material for the annular channel for 300 mN SPT, (f) Technology handing over ceremony to LPSC in presence of Director VSSC (Currently Chairman ISRO).

material is finally developed and showed 20% less erosion compared to the imported anode liner material maintaining all other required properties. To celebrate this achievement, a technology handover ceremony was arranged on 27.12.2021 by VSSC in presence of Director VSSC, Director LPSC (Bangalore and Thiruvananthapuram), Director CEERI, M/s Bhukhanvala Pvt.Ltd, and Dean IPR, Heads PSED and APD,IPR. Work done by IPR team (figure 2 d) was appreciated by all the Directors.

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Electro-static Discharge in Solar Coupons under LEO Plasma Conditions

Electro Static Discharge (ESD) is a common phenomenon in satellites due to surface charging by low density plasma present in Lower Earth Orbit (LEO). Such ESD events may generate minor or sustained arc in the solar panel that may lead to permanent failure of the satellites [1]. Therefore ground experiments were simulated at IPR lab to reproduce the similar arcing events as occurred in space. For this purpose Space Plasma Interaction Experimental facility was developed indigenously equipped with LEO like plasma source (filamentary discharge), plasma diagnostics, power supplies, arc counting circuit and CCD cameras. Primary focus was to investigate the prominent arcing locations in solar panel, arc threshold voltages, arcs statistics and underlying physics (figure 1). All the experiments were very time consuming typically running for 5-8 hrs. Hundreds of such arc movies and oscilloscope traces were recorded during the project to generate large statistics of such arcs. Experiments concluded several useful suggestions for ISRO to mitigate the arc initiation and improve solar panel life time for satellites. It was found that thermal, plasma curing and grouted coupons drastically reduce the number of arcs (figure 2) [1,2]. This facility is still in use for solar coupon testing for EDS events.

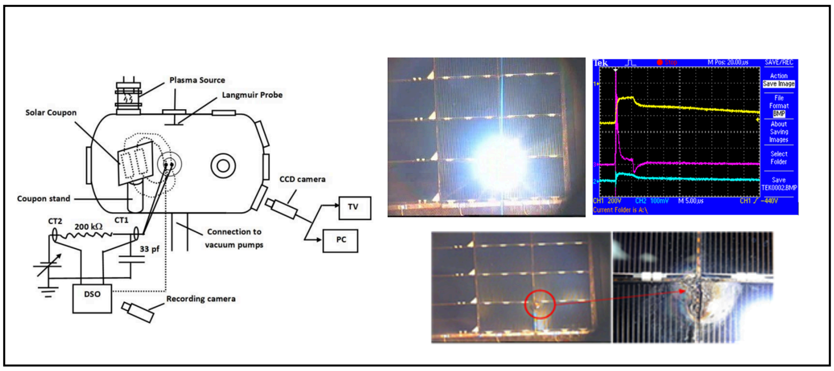

Figure 1: Developed facility, DSO traces, Evolution of the major Arc (SAS = 80 V, Bias = -407 V), arc locations

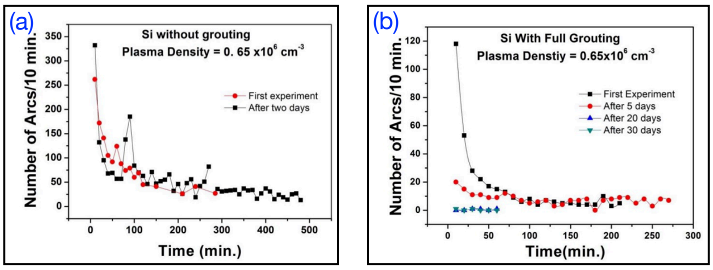

Figure 2: Effect of grouting on number of arc events occurring on the panel surface. Number of arcs are more in (a) as compared to (b) in this case panel gap and connectors were covered with grouting

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The technologies listed under this section are in the development phase. The proof of concept of these technologies is established. Both theoretical and computational modelling studies, as per requirement, are underway to validate them. Detailed experiments and observations are needed to validate these systems in different environments. Efforts are being made to develop these technologies for potential and specific applications. For more specific and complete details, please contact ptts@ipr.res.in.

VERY LOW PRESSURE PLASMA SPRAYING

Plasma Torch and Very Low Pressure Plasma Spraying Applications

The plasma torch program at Institute for Plasma Research (IPR) dates back to the early 1990s. In the initial phase, research mainly involved developing plasma torches for different applications. With focus shifting to disposal of solid waste, especially bio-medical waste, the emphasis was on developing easy to fabricate graphite based torches that did not require water cooling and were much more energy efficient. This program is matured into what we now know as plasma pyrolysis program. However, several technology areas still required the use of plasma torches without the use of graphite electrodes. The idea was to develop high power torches with non-expendable type electrodes and an environment devoid of pollutants other than those involved in the process itself. With this in mind, the plasma torch program was revived about a decade and a half ago. The activities started with a deep understanding of dynamics of the plasma torches. This comprised of development of semi-empirical formulations, three dimensional computer models as well as fundamental studies. Understanding of the plasma dynamics was developed using a clever combination of several diagnostics such as electrical and magnetic techniques, fast imaging and spectroscopy. Several research papers were published by the group comprising of a scientist and research scholars [1 – 4]. High power (~100 kW), high efficiency (~70 - 80%) torches and enthalpy probes were also developed. Photograph of a high power plasma torch developed at IPR, is shown in figure 1.

With the understanding firmly in place, the focus shifted to applications. At present, a major focus area is to develop the capability of depositing a wide spectrum of columnar structured coatings on different types of substrates. Plasma spray processing is a major technique in materials engineering because it offers affordable and effective thin film and coating technology. However, demands of the rapid advances made in sectors like electronics, automotive, aerospace, biomedical etc. cannot be met by current technologies. Therefore, there is a need of a new technique for thermal

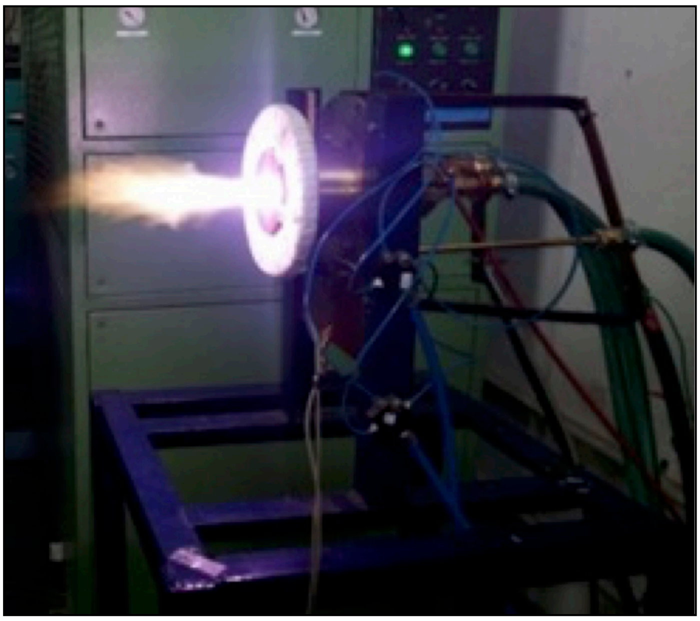

Figure 1: High power (85 kW) plasma torch in operation

spraying of specialized coatings at a rapid pace. The technique presently being developed offers to bridge the gap between conventional plasma vapour deposition and atmospheric plasma spray by combining high deposition rates and cost-efficiency of thermal spraying and features of plasma vapour deposition to deposit wide spectrum of coatings, with the unique capability to deposit coatings on non-line-of-sight areas of substrates with complex geometries. This is a new technique and is being investigated by some other research laboratories across the world too. The activities involve design and development of high power plasma torches for operation at very low pressures and identification of appropriate plasma parameter regime. At very low pressures, the plasma torch emanates a supersonic plasma plume (shown in figure 2). Optimization of parameters, controlling the rate of feedstock introduction and vaporization and characterization of the coatings are also part of the activity.

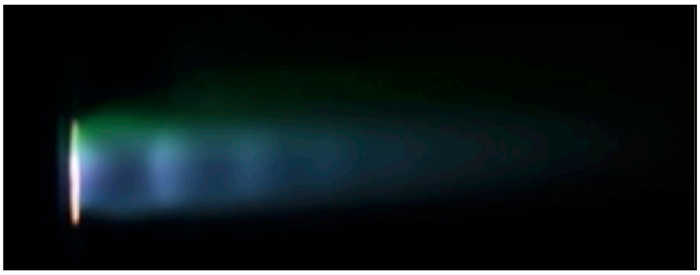

Figure 2: Photograph of Supersonic plasma plume captured using fast imaging camera

In recent experiments, the effect of chamber pressure on the electrical and thermodynamic characteristics of a low-pressure thermal plasma jet was studied and major findings have been reported in a series of publications [5 – 7]. The focus of the study lies on the experimental investigation of the current–voltage characteristics, arc voltage fluctuations, plasma jet temperature, electron density, and velocity within the range of 100 – 500 A arc current at chamber pressures of 100 Pa, 1 kPa, and 3 kPa. The electrical characterization reveals the presence of distinct frequencies including restrike, Helmholtz, and acoustic modes through spectral analysis of the arc voltage [1]. Variation of light intensity, excitation temperature, electron temperature, and Mach number with axial distance at different operating pressures is shown in figure 3.

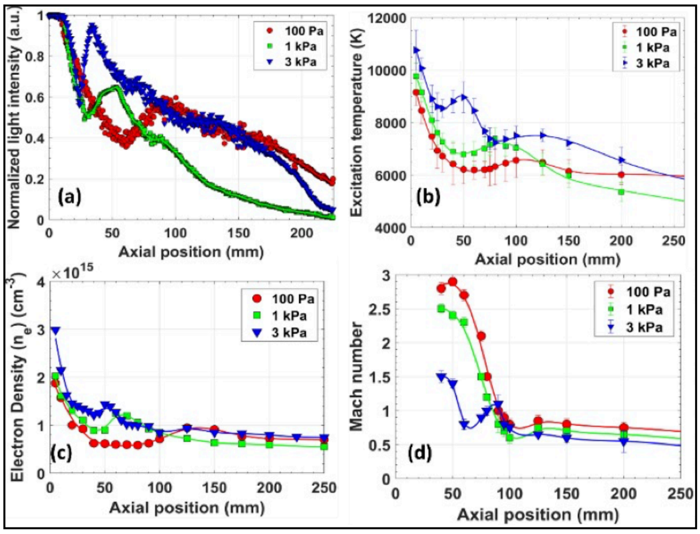

Figure 3: (a) Normalized light intensity profile (b) Excitation temperature profile (c) Electron density profile (d) Mach number profile of the plasma jet at r=0 and different axial locations, Nitrogen flow rate= 50 LPM, arc power = 30 kW, arc current = 500 A

The studies primarily focus on the investigation of arc fluctuation behaviour under very low pressure conditions. This is because arc root fluctuations play a critical role in determining both the arc voltage and heat transfer to the feedstock (coating material) in a plasma torch and can also affect the temperature distribution and deposition rate. In spite of extensive research on the investigation of the influence of chamber pressure on the properties of the plasma jet, particularly within the higher pressure range, there is a significant knowledge gap regarding the behaviour of the plasma jet within the very low-pressure to low-pressure regime. The studies have also explored the transition of the plasma jet from a continuum regime to a frozen state with decreasing chamber pressure, along with the formation of shock structures. The results (figure 3 & 4) demonstrate that the jet temperature and density peak at the compression zone.

Mach probe measurements of the plasma jet velocity at different axial locations, under various chamber pressure conditions, illustrate that the supersonic state of the plasma jet is maintained, regardless of

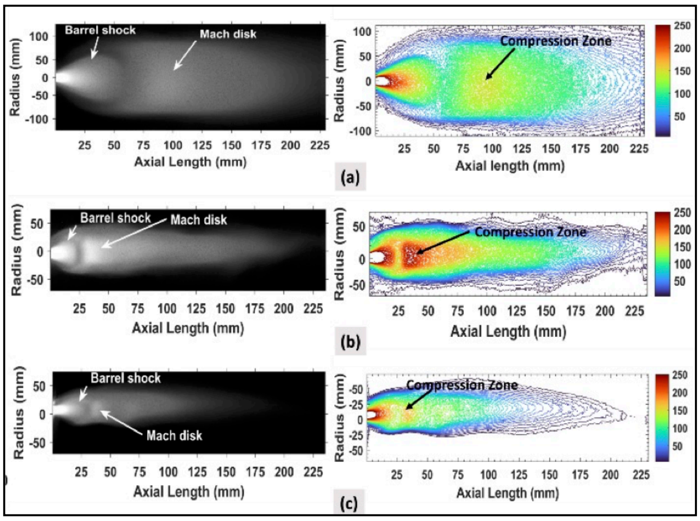

Figure 4: Evolution of plasma jet images and their respective iso-contour profile for 50 LPM N2 flow rate and 500 A at (a) 100 Pa (b) 1 kPa, and (c) 3 kPa chamber pressure.

chamber pressure. The results greatly enhance our understanding of thermal plasma jets under low to very low pressure conditions, with an emphasis on formation of structured thermal barrier coatings.

Formation of 100 mm thick thermal barrier coatings (60 mm YSZ + 40 mm bond coat of NiCrAlY) on stainless steel substrates were demonstrated using this very low pressure plasma spray technique. Coatings were formed at the rate of 20 mm/min using a 60 kW plasma torch at an ambient pressure of 1 mbar and characterized using FE-SEM and XRD. Current activities involve optimization of engineering parameters for desired coatings, in-depth understanding of powder-plasma interaction, generation of database of experimental parameters for different types of feedstock and various types of coatings, e.g. laminar, columnar, mixed etc.

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2. Yugesh, Vadikkeettil, Ganesh Ravi, Kandasamy Ramachandran, Goyal Vidhi, and Kailsha Chandra Meher. "Influence of the shroud gas injection configuration on the characteristics of a DC non-transferred arc plasma torch." *Plasma Chemistry and Plasma Processing* 38 (2018): 759-770.
3. Vadikkeettil, Yugesh, Ganesh Ravi, and Kandasamy Ramachandran. "Prediction of operational characteristics of a dc non-transferred arc plasma torch using similarity criteria." *The European Physical Journal D* 71 (2017): 1-10.
4. Goyal, Vidhi, G. Ravi, P. Bandyopadhyay, S. Banerjee, V. Yugesh, and S. Mukherjee. "Study of dynamical behaviour of the plasma in a dc non-transferred plasma torch using fast imaging." *Physics of Plasmas* 24, no. 3 (2017).
5. Mohanta, Ram Krushna, and G. Ravi. "Investigation of subsonic to supersonic transition of a low-pressure plasma torch jet." *IEEE Transactions on Plasma Science* 50, no. 9 (2022): 2941-2951.
6. Mohanta, Ram Krushna, Devilal Kumawat, G. Ravi, and Kumudni Tahiliani. "Application of similarity theory to predict operational characteristics of a DC plasma torch under low-pressure condition." *The European Physical Journal D* 77, no. 5 (2023): 89.
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An Eco-friendly Technology for the Surface Activation of Carbon Granules at Atmospheric Pressure for Water Filtration Applications

Introduction

Water filter is the cheapest and most feasible solution for water treatment to get clean water. Most commonly used water filter candles are made of activated carbon granules. Carbon granules are natural materials derived from bituminous coal, lignite, wood, or coconut shell etc. Chemical and physical treatments of carbon granules have been successful in producing the activated carbon which is used as a cheapest means of water filtration application. Surface of the conventionally activated carbon granules is hydrophobic in nature. And because of this, the activated carbon requires a pressuring system to filter the water through it which is mostly fulfilled by electrical pumps. In some cases, a water tank of a few meters height is required to produce the necessary pressure. Hence, water filter candles made out of conventionally activated carbon cannot be used at normal pressure which is just due to gravity. And due to this limitation, people cannot use these candles in the remote inhabitations in developing countries.

Work done at Institute for Plasma Research (IPR)

With the objective of improving the water absorbing property of carbon powder, FCIPT, IPR took up a challenge to develop a plasma based technology as a dry & clean process for converting the carbon granules into more hydrophilic and to filter the water at gravity pressure, in collaboration with M/s Filtrex Technologies, Bangalore. Majority of the plasma processing activities generally operate at pressures lower than atmospheric pressure. However, considering the difficulty of handling the carbon powder in a low pressure system, a new eco-friendly technology for the surface activation of carbon granules at atmospheric pressure, using dielectric barrier discharge (DBD) configuration was developed. An image of the DBD discharge is shown in figure 1.

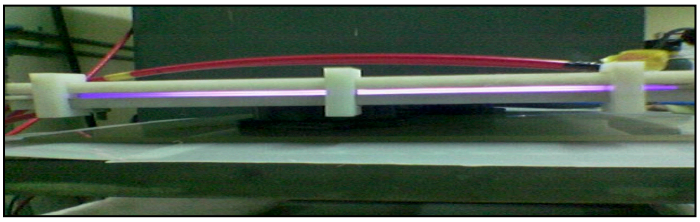


Figure 1: A uniform plasma discharge between two electrodes of dielectric barrier discharge (DBD) operating at atmospheric pressure

The indigenously developed DBD system comprising of specially designed mesh electrodes, HV power supply, rollers, carbon powder loading conveyer belt was successfully designed, developed and finally commissioned at M/S Filtrex Technology, Bangalore; in a very short time period of 8 months. A photograph of the DBD plasma treatment system developed at FCIPT, IPR, is shown figure 2.

Figure 2: A complete view of developed DBD plasma system

Result and discussion

Various experiments were conducted using different quantity of conventionally activated granular carbon [as received from M/S Filtrex Technologies, Bangalore] to determine the effects of the plasma treatment on surface wettability, morphology and chemical composition. The gaseous media used for all the experiments was normal air, which makes the system simpler and cost effective. To prove the improvement in hydrophilic behaviour, the consequences of the surface changes were demonstrated by visual methods. In order to demonstrate the increase in hydrophilic nature, both treated and untreated powders were poured in two different transparent glasses (containing normal tap water). It was noticed that untreated powder floats over the water surface and treated powder settles down at the bottom of glasses as shown in figures 3 and 4. This visual observation confirmed that the plasma treatment increases the hydrophilic property of the conventionally activated carbon granules.

Figure 3: Top view showing floated untreated carbon powder (Left) and treated carbon powder is settled at the bottom (Right)

Figure 4: Side view of glasses is showing the untreated floated powder (Left) and dissolved treated powder (Right)

Development of CZTS Absorber based Thin Film Solar Cell

While looking for a Solar Photovoltaic Technology there are few things to be considered:

- Indigenous Technology
- User Friendly Industrial Technology (easy to make & scale up for large area)
- Toxic Free material (no disposal issues)
- Abundantly available material (for future sustainability)
- Stable with time (i.e., no degradation)
- Low cost production

Cu_2ZnSnS_4 (CZTS) having an optimum bandgap of ~1.5 eV and high absorption coefficient of 10^4 cm^{-1} is a suitable candidate for absorber material in thin film solar cell because of its reasonable performance and earth abundant constituents.

Magnetron Sputtering is a well proven technology in Industry for large area coatings for different application including solar cell applications. Development of this type of solar cell using sputtering method is our main focus at Institute for Plasma Research (IPR), for higher efficiency CZTS absorber based solar cell. So, here we are working for an indigenous, industry friendly, user friendly and low cost technology for solar photovoltaic applications.

The step wise, layer by layer deposition of the device is shown in figure 1. Typical optimized properties of all the layers are summarized in table 1. With this optimization, a 5% efficient solar photovoltaic device is made at IPR. The scanning electron microscopic (SEM) cross section image and I-V characteristics of the device are shown in figure 2. Further research work is in progress at FCIPT, IPR to further increase the device efficiency.

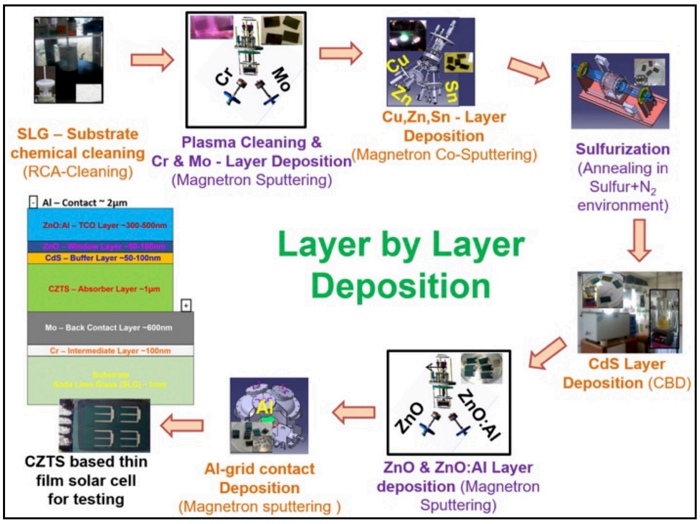


Figure 1: Deposition process of CZTS thin film solar cell

ZnO:Al Layer	Low Resistivity ~ <5x10^{-3}Ω-cm, High Transparency ~ >85%, E_g ~3.3eV
ZnO Layer	High Resistivity, High Transparency ~ >90%, E_g ~3.3eV
CdS Layer	High Resistivity, High Transparency ~ >80%, E_g ~2.3eV
CZTS Layer	High Absorption Coefficient ~ >10^{4}cm^{-1}, E_g ~1.5eV
Mo Layer	Very Low Resistivity ~ <5x10^{-5}Ω-cm, Stable during device fabrication
Cr Layer	For Adhesion Improvement, Stable during device fabrication

Table 1: typical optimized properties of the various layers of CZTS thin film solar cell

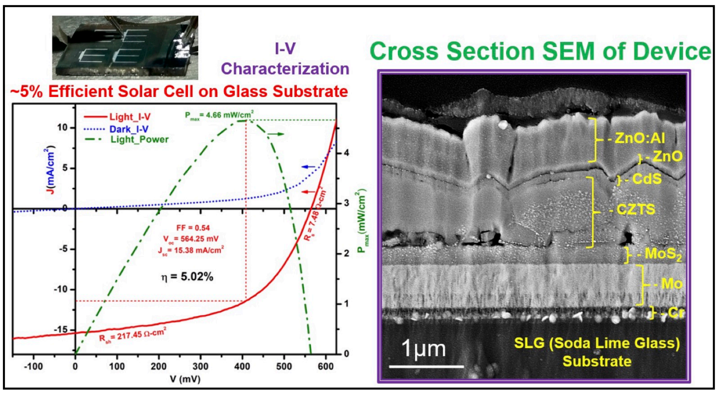


Figure 2: I-V characteristics and cross section SEM image of the device

Plasma Immersion Ion Implantation System

Introduction

Ion implantation is a surface-sensitive technique in which ions of an element are accelerated and forced to penetrate into the surface of a solid material in order to modify its surface properties. In this process, typically, ion energy ranges from a few hundreds of eV to a few hundreds of keV. Unlike diffusion based surface modification processes, ion implantation can operate at lower temperatures also. The technique finds much use in semiconductor industry and in materials science applications. In the semiconductor industry, ion implantation is used for enhancing semiconductor properties by introducing dopants, with precision control, to create p-type or n-type regions. Other than traditional doping applications, ion implantation is also applied in semiconductor fabrication for example in the fabrication of sensors and electronic devices. In materials science applications mostly N+, Ar+, He+, C+, and metal ions are used for implantation. Using this technique chemical, physical, and structural properties of the materials' can be greatly improved. Moreover, this technique does not require objects to be heated to high temperatures – as is required in diffusion based processes – which helps ensuring the dimensional accuracy and smoothness of the objects even after implantation.

In conventional ion implantation technique, ions are generated by physical means and the ion beam is rapidly accelerated towards the object for the required implantation. This is a line-of-sight process and hence difficult to use for the implantation of complex 3D shaped objects. Plasma based implantation can play a positive role in such cases.

In Plasma Immersion Ion Implantation (PIII) technique, the objects to be implanted are fully surrounded by a plasma of relevant gases and gas mixtures. The plasma acts as a source of required ions which will then be accelerated towards the object, by biasing the objects to high negative pulsed voltages. As the plasma can be uniformly created around even complex shaped objects, this technique can ensure more uniformity in implantation.

Work being done at Institute for Plasma Research (IPR)

At IPR, we are developing a lab scale PIII system. In this system, experiments can be carried out for studying the feasibility of implanting simple gaseous ions in to various substrate samples (of Aluminium, Steel, Copper etc.). Ions with energies up to ~15 keV can be generated in this system. A photograph of the system is shown in figure 1.

The experimental system is a vacuum compatible system made out of stainless steel. A combination of rotary and diffusion pumps is used for obtaining the necessary base & operating pressures. A solid state RF generator (13.56 MHz, 1000W) along with an automatic matching network is part of the PIII system, and is used for generating the required plasma. A DC power source is used for preparatory etch-cleaning of the samples. A high voltage negative pulsed power source is used for applying the necessary bias voltage to the substrate samples. Pulse ON time and frequency can be varied with sharp rise and fall times of the pulse. Inside view of the experimental system is shown in figure 2.

Conclusion

At present, we are carrying out feasibility studies of modifying surfaces of Aluminium and its alloys by implanting them with Nitrogen ions. The objective is to form AlN (Aluminium Nitride) on the surface for achieving better tribological, electrical and mechanical properties.

Figure 1: Photograph of the PIII system

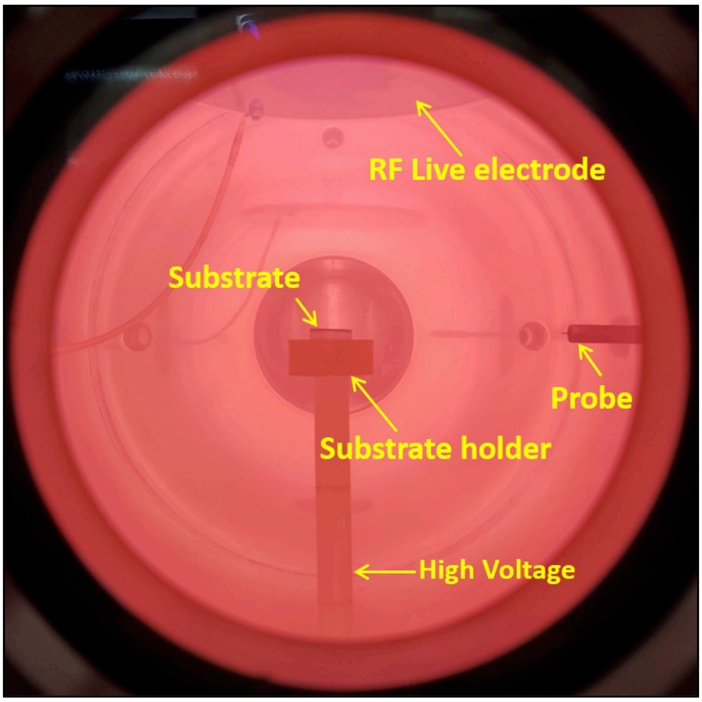


Figure 2: The inside view of the PIII system

Plasma based Air Sanitization System for Inactivation of Air borne Pathogens

In recent years, particularly after the Covid pandemic, the importance of air quality in both indoor and outdoor environments has gained significant attention due to its impact on human health and well-being. The air we breathe contains various contaminants including particulate matter, volatile organic compounds (VOCs), allergens, and microbes, which can adversely affect respiratory health and overall wellness. Hence, the demand for effective air purification solutions has escalated.

Plasma air purifiers have ability to effectively remove various types of pollutants from the air, including allergens, bacteria, viruses, and odour causing molecules. They can improve indoor air quality, which can be particularly beneficial for individuals with allergies, asthma, or respiratory issues. Recently, Institute for Plasma Research (IPR), in collaboration with Centre for Cellular and Molecular Platforms (C-CAMP), has co-developed a cold atmospheric plasma (CAP) based air disinfection device.

The application of plasma for air sanitization involves generating reactive species that can effectively deactivate or destroy airborne pathogens. The efficacy of this device has been tested on multiple organisms (ESKAPE range, phage and fungal strain) in an NABL accredited lab under ISO specified protocols in a test room of about 6 m^3 volume. More than 99% reduction in microbial load was achieved within few minutes (~5 minutes), using this device. This device has been tested in an AC bus coach and has shown a 2 log reduction of microorganisms. Results are shown in figure 1. The Air Purifier met the requirements as per customer protocol based on ISO 16000 (part 36): 2018 for the efficacy against the Bacteria, E.coli (ATCC 11229) for about more than 2 log reduction (99%) at 18 minutes of settling time, after exposure of microorganism. This device has good potential to be used in hospitals/clinics.

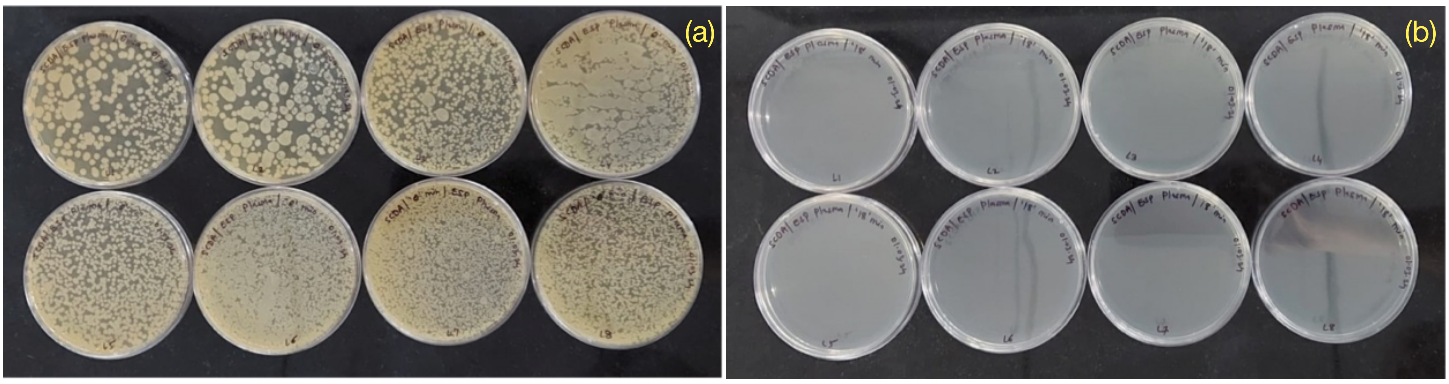


Figure 1: (a) before plasma treatment (b) after plasma treatment showing 2 log reduction (99%) of E.coli microorganism

Plasma Teflon Coating on Steel Shells and Inflatable Seals

Introduction

Anti-friction coatings find multitude of applications in engineering industry. These coatings are important due to their ability to reduce friction, wear, and corrosion between moving parts. They play a significant role in reducing wear and tear, help enhance energy efficiency, and improve the overall performance of the machinery. Most of the anti friction coatings provide protection against corrosion too. They typically find applications in automotive, aerospace industry etc. Teflon or PTFE (polytetrafluoroethylene) is one of those materials with very low coefficient of friction among solid materials. Further, it is highly resistant to a wide range of chemicals, making it suitable for harsh industrial environments. Therefore teflon or teflon like coatings can be one of the best choices for anti friction requirements.

Work done on Teflon like coatings at Institute for Plasma Research (IPR)

At IPR, work was initiated on the development of Teflon based anti-friction coatings for a specific requirement from Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam. The objective was to develop Teflon like anti-friction coatings over the outer surface of inflatable seals (polymer materials), and on the inner surfaces of carbon & stainless steel shells. The inflatable seals were of different sizes while the size of the steel shells was of 2 m diameter. The inflated seals would rub against the inner surfaces of the shells in the actual reactors. Size of the seals and shells, in the actual reactor, would be larger. Both these inflatable seals and the carbon & stainless steel shells are required to be deposited with coatings with very less coefficient of friction (~ 0.1 to 0.2), and with good adhesion. Teflon coating seems to be best suited for this requirement. Conventionally, lacquer spray techniques are used for obtaining these coatings, however, there is a possibility of porosity and higher coefficient of friction with them.

At IPR, Plasma Enhanced Chemical Vapour Deposition (PECVD) technique was successfully used for depositing Teflon-like coatings. Required monomer was generated in-house using an innovative process of pyrolyzing Teflon tailings in a controlled environment.

After optimizing process parameters at lab-scale, a PECVD based coating system for depositing Teflon-like coatings on up to 7 meter diameter seals, was designed, fabricated and commissioned at FCIPT (Facilitation Centre for Industrial Plasma Technologies), a division of IPR. Photograph of the developed coating system is shown in figure 1. A Parallel plate configuration with a customized shower-head was specifically designed for this purpose.

Further, a unique box coater with gas shower-head cum live electrode mechanism was developed for depositing Teflon-like coating on Carbon & Steel shells. The designed box coater could deposit the necessary coating over a section of the shell, and the entire shell was deposited with the coating in multiple batches. Figure 2 shows the schematic diagram of the setup for depositing the coating,

Figure 1: PECVD based coating system developed for coating large seals

whereas photograph of the entire shell deposited with Teflon like coating in the designated area is shown in figure 3. It is ensured to maintain coating uniformity at the overlapping areas of the coating regions deposited in each batch.

Conclusion

Institute for Plasma Research has developed PECVD based systems for depositing Teflon like coatings on seals and Steel shells. Coatings were successfully deposited on the steel shells of two meter diameter in size. However, there is a scope for improvement in optimizing process parameter in the context of sustaining the coating quality over long durations and also in harsh environments. Further, deposition of Teflon like coating on actual seals could not be persuaded due to non-availability of uniformly inflated seals.

Suggested Reading

1. Satyaprasad, A., S. K. Nema, N. K. Sinha, and Baldev Raj. "Deposition of thick and adherent Teflon-like coating on industrial scale stainless steel shell using pulsed dc and RF PECVD." *Applied surface science* 256, no. 13 (2010): 4334-4338.

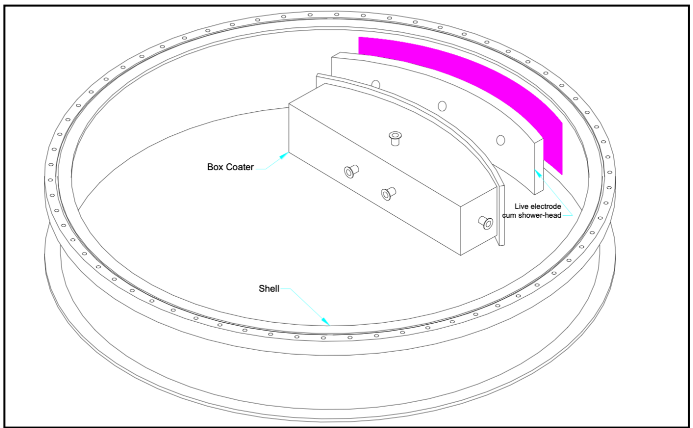


Figure 2: Schematic diagram of the box coater, live electrode and the shell

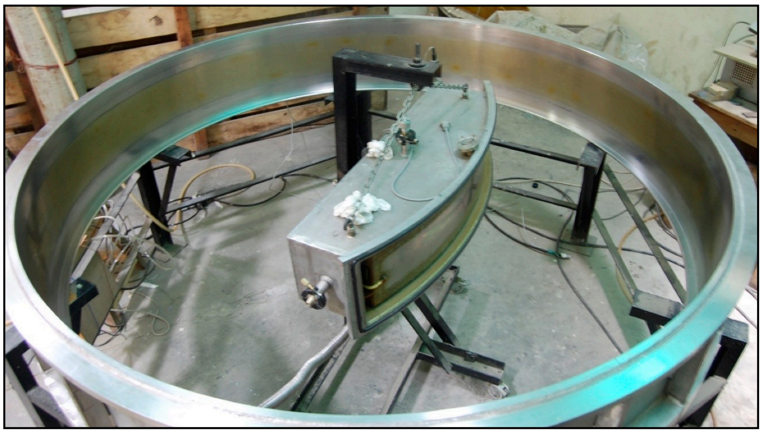


Figure 3: Stainless steel shell deposited with Teflon-like coating in the defined area of its inner surface. Box coater is also seen in the picture

TECHNOLOGY TRANSFERS / MoUs signed

Following is the list of a few technologies developed at Institute for Plasma Research, the knowhow of which was transferred to several companies on non-exclusive basis (after 2010). Interested people may please contact ptts@ipr.res.in for further information.

1. Plasma Pyrolysis Technology for Organic waste

A. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Organic waste" was signed between IPR and M/s B. L. Engineering, Ahmedabad, Gujarat; in 2015.

B. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Organic waste" was signed between IPR and M/s Bhakti Energy, Rajkot, Gujarat; in 2016.

C. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Organic waste" was signed between IPR and M/s G. P. Green Energy Systems Pvt. Ltd., Kolkata, West Bengal; in 2016.

D. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Organic waste" was signed between IPR and M/s Excel Industries Ltd., Mumbai, Maharashtra; in 2022.

Tech. Transfer between IIPR and M/s B. L. Engineering

2. Plasma Pyrolysis Technology for Bio-medical waste

A. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Bio-medical waste" was signed between IPR and M/s Ankur Scientific Energy Technologies Pvt. Ltd., Vadodara, Gujarat; in 2020.

B. Technology knowhow and license agreement for "Plasma Pyrolysis Technology for Bio-medical waste" was signed between IPR and M/s Bhakti Energy, Rajkot, Gujarat; in 2023.

Tech. Transfer between IPR & M/s Ankur Scientific Energy Technologies Pvt. Ltd.

Tech. Transfer between IPR & M/sBhakti Energy

TECHNOLOGY TRANSFERS / MoUs signed

3. Plasma Nitriding

(A) Technology knowhow and license agreement for "Plasma Nitriding Technology" was signed between IPR and M/s Therelek Engineers Pvt. Ltd. , Bangalore, Karnataka; in 2016.

4. Metal Oxide Nano-powder Production Technology

(A) Technology knowhow and license agreement for "Metal oxide nano powder production technology" was signed between IPR and M/s Plasma & Vacuum Techniques, Ahmedabad, Gujarat; in 2016.

(B) Technology knowhow and license agreement for "Metal oxide nano powder production technology" was signed between IPR and M/s Vishal Engineers & Galvanisers Pvt. Ltd., Ahmedabad, Gujarat; in 2017.

(C) Technology knowhow and license agreement for "Metal oxide nano powder production technology" was signed between IPR and M/s Rubamin Ltd., Vododara, Gujarat; in 2019.

(D) Technology knowhow and license agreement for "Metal oxide nano powder production technology" was signed between IPR and M/s FCG Hi-Tech Pvt. Ltd., Mumbai, Maharashtra; in 2022.

Tech. Transfer between IPR and M/s Plasma & Vacuum Techniques

Tech. Transfer between IPR and M/s Vishal Engineers & Galvanisers Pvt. Ltd.

Tech. Transfer between IPR and M/s Rubamin Ltd.

Tech. Transfer between IPR and M/s FCG Hi-Tech Pvt. Ltd.

5. Plasma Activated Water (PAW) Generating System

(A) Technology knowhow and license agreement for "Plasma Activated Water Generating System" was signed between IPR and M/s Persapien Innovations Pvt. Ltd., New Delhi; in 2021.

(B) Technology knowhow and license agreement for "Plasma Activated Water Generating System" was signed between IPR and M/s Pruthvi Beverages Private Limited, Gandhinagar; in 2022.

TECHNOLOGY TRANSFERS / MoUs signed

Tech. Transfer between IPR and M/s Pruthvi Beverages Pvt. Ltd.

Tech. Transfer between IPR and M/s Persapien Innvoations Pvt. Ltd.

6. DBD Plasma Technology for Angora Wool Treatment

(A) Technology knowhow and license agreement for "DBD Plasma Technology for Angora Wool Treatment" was signed between IPR and M/s Inspiron Engineering Pvt. Ltd., Ahmedabad, Gujarat; in 2011.

(B) Technology knowhow and license agreement for "Atmospheric pressure inline Plasma Treatment Technology" was signed between IPR and M/s Arshad Electronics Pvt. Ltd., Mumbai, Maharashtra; in 2016.

Tech. Transfer between IPR and M/s Arshad Electronics Pvt. Ltd.

7. Glow Discharge Plasma System with Langmuir probe

(A) Technology knowhow and license agreement for "DC glow discharge Plasma system with Langmuir probe diagnostics" was signed between IPR and M/s Sun Vacuum & Plasma Engineering, Ahmedabad, Gujarat; in 2023.

Tech. Transfer between IPR and M/s Sun Vacuum & Plasma Engineering

8. Atmospheric Pressure Plasma Jet for Bio-medical Applications

(A) Technology knowhow and license agreement for “Atmospheric Pressure Plasma jet for Bio-medical Applications ” was signed between IPR and M/s Aditiya High Vacuum Pvt. Ltd , Ahmedabad, Gujarat; in 2016.

Tech. Transfer between IPR and M/s Aditya High Vacuum Pvt. Ltd.

9. AGASTYA Cryopump Technology

(A) Technology knowhow and license agreement for "AGASTYA Cryopump Technology" was signed between IPR and M/s Cenerge Engineering Solutions, Mumbai, Maharashtra; in 2022.

(B) Technology Knowhow and license agreement for "AGASTYA Cryopump technology" was signed between IPR and M/s Precise Vaccum Pvt. Ltd., Nashik, Maharashtra; in 2022.

Tech. Transfer between IPR and M/s Cenerge Engineering Solutions

Tech. Transfer between IPR and M/s Precise Vacuum Pvt. Ltd.

10. DC Pulsed power Technology

(A) Technology knowhow and license agreement for “DC Pulsed power Technology" was signed between IPR and M/s Auto Controls, Mumbai, Maharashtra; in 2013.

11. Regulated High Voltage Power Source

(A) Technology knowhow and license agreement for “Regulated High Voltage Power Source" was signed between IPR and M/s Electronics Corporation of India Ltd., Hyderabad; in 2012.

12. Advanced shaped Hydroformed panels for Gas sorption Unit

(A) Technology knowhow and license agreement for "Advanced shaped Hydroformed panels for Gas sorption Unit" was signed between IPR and M/s I-Design Engg. Solutions Ltd., Pune, Maharashtra; in 2012.

13. SERS

(A) IPR has entered into a collaboration for "Supplying SERS Substrates", with M/s New Age Instruments and Materials Pvt. Ltd., Gurgaon, Haryana; in 2024.

(B) IPR has entered into a collaboration for "Supplying SERS Substrates", with M/s Labindia Instruments Pvt. Ltd., Mumbai, Maharashtra; in 2024.

MoU between IPR and M/s Labindia Instruments Pvt. Ltd.

PATENTS

List of a few relevant patents & copyrights (applied/granted), by Institute for Plasma Research is presented below.

1. **System and Method for Air Disinfection**, Saiyed T, Choudhury K, Patel P, Joseph A, Rane R, Vaid A, Visani A, Indian Patent Application number 202341063410, filing date: 20/09/2024
2. **A Novel System for Online Microscopic Image Examination**, Agraj Abhishek, Abhishek Sharma, Manika Sharma, Naveen Rastogi, Jignesh P. Chauhan, K. K. Gotewal, Indian Patent Application number 202421058089, filing date: 31/07/2024
3. **A Novel Dental Medium for Storage and Transportation of Avulsed Teeth**, Yash Bafna, Shoba Fernandes, S. K. Nema, Vikas Rathore, Chirayu N. Patil, Matangi Joshi, Indian Patent Application number 202421018111, filing date: 31/07/2024
4. **A Process for Producing Superhydrophobic Metallic Surface for Efficient Water Harvesting**, Vivek Pachchigar, Basanta Kumar Parida, Mukesh Ranjan, Sooraj K. P., Indian Patent Application number 202421057885, filing date: 30/07/2024
5. **Plasma Sterilization System and Process to Sterilize Medical Components and Devices Using Microwave Source**, K. Nigam, G. Ravi, S. K. Nema, T. Barkhade, C. Patil, B. Sahoo, Indian Patent Application number 202421018111, filing date: 13/03/2024
6. **A Rapid, Low-Cost Process for the Preparation of Surface Enhanced Raman Spectroscopy (SERS) Substrate and SERS Substrate Prepared Thereby**, M. Ranjan, S. Augustine, K. P. Sooraj, M. Saini, S. Hans, V. Pachchhigar, B. K. Parida, Indian Patent Application number 202321081756, filing date: 01/12/2023
7. **A system and Method for Air Disinfection**, J. Alphonsa, R. Rane, A. Vaid, A. Visani, Indian Patent Application number 202341063140, filing date: 20/09/2023
8. **A plasma based system for generating antimicrobial coating on flexible polymeric substrates and process thereof**, R Rane, A. Vaid, J. Alphonsa, N. Jamnapara, US Patent Application No. 18/450,956, filing date: 16/08/2023
9. **A serverless and offline document signing and verification using networking and cryptography library (NaCl)**, Agraj. Abhishek, Abhishesk. Sharma, Manika Sharma, Applied for Copyright, Diary No. 11601//2022-CO/L, Date: 01.06.2022
10. **A system to generate repetitive shock wave through automatic successive wire explosions**, V. Jain, B. K. Patel, C. Patil, A. Reddy, R. Bhatiya, Indian Patent Application number 202321055574, filing date: 30/08/2021
11. **An apparatus to generate large plasma arc plume for waste disposal and thermal processing applications**, V. Jain, S. K. Nema, Adam B. Sanghariyat, Chirayu Patil, Bhupendra Patel, Atikkumar N. Mistry, Indian Patent Number: 432380, filing date: 30/08/2021
12. **A Method for increasing the life of Cutting Tools**, Alphonsa Joseph, Ghanshyam Jhala, Akshay Vaid, and Subroto Mukherjee, Indian Patent Number: 488119, filing date: 15/06/2018
13. **Splitted Plasma Anode Fire-ball based Ion Source for both Nanopatterning and Thin film deposition**, Mukesh Ranjan, Tapan Barman, Samirsinh Chauhan, Akshay Vaid, and Subroto Mukherjee, Indian Patent Number: 413565, filing date: 07/06/2018

PATENTS

14. **An apparatus for water treatment to activate water using atmospheric pressure hybrid plasma system**, Sudhir Kumar Nema, Vishal Jain, Adam Sanghariat, Subroto Mukherjee, Nirav Jamnapara, Indian Patent Number: 460455, filing date: 20/12/2016
15. **A system and method for preparation of the metal oxide nano particles**, C. Balasubramanian, Adam Sanghariat, Chirayu Patil, Subroto Mukherjee, Indian Patent Number: 467608, filing date: 26/05/2016
16. **Atmospheric Pressure Plasma Jet for Bio-Medical Applications**, Akshay Vaid, Patil Chirayu, Adam Sanghariat, Ramakrishna Rane, Abhijit Majumdar, Subroto Mukherjee, Indian Patent Number: 497593, filing date: 30/09/2015
17. **A system to generate high power density dielectric barrier discharge plasma in ambient air medium**, Vishal Jain, Anand Visani, Adam Sanghariat, Sudhir Kumar Nema, Subroto Mukherjee, Indian Patent Number: 408755, filing date: 21/05/2014
18. **An apparatus for treating matter using inductively coupled plasma**, Vishal Jain, Anand Visani, Bhupendra Patel, Chirayu Patil, Sushir Kumar Nema, Pradyumansinh Jhala, Indian Patent Number: 426773, filing date: 30/01/2013
19. **An apparatus for production of microwave plasma**, V. Jain, A. Visani, B. K.Patel, P. K. Sharma, C. Patil, P. I. John, S. K. Nema, Indian Patent Number: 375337, filing date: 31/12/2012
20. **A process for plasma oxidation of a substrate and an apparatus therefor**, Nirav I. Jamnapara, Suryakant Gupta, Subroto Mukherjee, Indian Patent Number: 304083, filing date: 07/12/2011
21. **Plasma enhanced jet vapor deposition of metallic films**, Akkireddy Satyaprasad, Rane Ramakrishna, Joseph Alphonsa, Mukherjee Subroto, Indian Patent Number: 403977, filing date: 24/02/2010
22. **A process for plasma surface modification and sterilization of angora fibres**, S. K. Nema, Jhala P. B., N. Tanwani, Rane R., Sanghariyat Adam, Mukherjee S., Gandhi G. A., P. I. John, Indian Patent Number: 335045, filing date: 28/04/2008
23. **An apparatus for plasma surface modification and sterilization of materials**, S.K.Nema, N.Tanwani, Rane R.,Sanghariyat Adam S., Mukherjee S., Indian Patent Number: 336974, filing date: 28/04/2008
24. **Plasma pyrolysis system for safe disposal of organic waste using plasma torch with a novel endogenous gas source**, Vishal Jain. P. I. John, S. K. Nema, Adam Sangariyat, Indian Patent Number: 281257, filing date: 19/11/2007
25. **A plasma process for surface modification of brass to rubber bonding**, S. K. Nema, P. Kikani, Indian Patent Number: 260548, filing date: 03/06/2006
26. **Plasma pyrolysis system and process for the disposal of waste using graphite plasma torch**, K. S. Ganeshprasad, S. K. Nema, Vishal Jain, Indian Patent Number: 272122, filing date: 11/09/2005
27. **A device for pyrolysing polymers and hospital/ municipal/ chemical/ metallurgical wastes**, Ganesh Prasad, S. K. Nema, Kalpesh Modi, S. P. Akkireddy, Sanjeev Soni, P. I. John, Indian Patent Number: 195943, filing date: 21/08/2002
28. **An apparatus for conversion of waste polymers into polymeric protective barrier coating**, S. K. Nema, P. Kikani and P. I. John, Indian Patent Number: 195938, filing date: 14/08/2002
29. **An apparatus for forming an antireflection coating on a substrate and process thereof**, S. K. Nema, Ashish Chainani, P. I. John, Indian Patent Number: 193486, filing date: 22/04/1999

30. **An apparatus for the deposition of protective barrier polymer coating on the surface of the substrate and the process thereof**, S. K. Nema, S. Mukherjee, P. I. John, Indian Patent Number: 194499, filing date: 22/04/1999

31. **Plasma nitriding furnace**, P. I. John, Indian Patent Number: 187950, filing date: 25/01/1993

32. **An apparatus and process for forming a dc glow discharge at low pressures**, P. I. John, Indian Patent Number: 193684, filing date: 01/01/1990

PUBLICATIONS / TALKS DELIVERED (in the last three months)

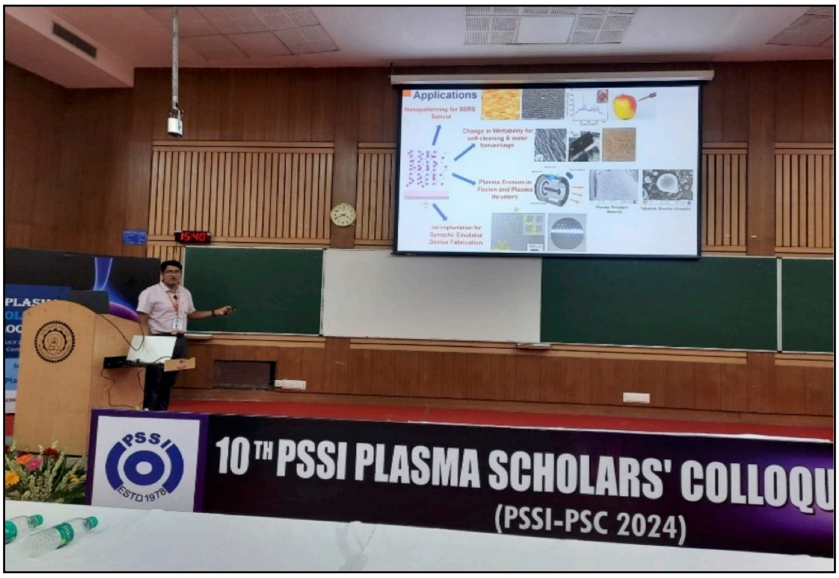
Publications in peer reviewed journals

1. Lamba, Tarundeep Kaur, Sebin Augustine, Mahesh Saini, K. P. Sooraj, and Mukesh Ranjan. "LSPR anisotropy minimization by sequential growth of Ag nanoparticles on nanoripple patterned Si surface for SERS Application." *Surfaces and Interfaces* 52 (2024): 104852.
2. Chandwani, Nisha, Himanshu Pandey, and Vishal Jain. "Underwater in-situ plasma treatment of coarse wool fibers for scouring and bleaching." *The Journal of The Textile Institute*(2024): 1-8.
3. Choudhary, Shipra, K. P. Sooraj, Mukesh Ranjan, and Satyabrata Mohapatra. "Facile synthesis, morphological, optical, catalytic and photocatalytic properties of Ag nanoparticles decorated Ce doped ZnO hybrid plasmonic nanorods." *Inorganic Chemistry Communications* 169 (2024): 113008.
4. Pathak, Nidhi, Ritu Kumari Pilania, Kandathil Parambil Sooraj, Mukesh Ranjan, and Charu Lata Dube. "The oxygen vacancies induced local surface plasmon resonance for NIR shielding in titanium-tungsten oxide doped borosilicate glasses." *Journal of Alloys and Compounds* 1004 (2024): 175887.
5. Trivedi, Kunal, Ramkrishna Rane, Alphonsa Joseph, Supratik Roychowdhury, M. Kiran Kumar, and Vivekanand Dubey. "Adhesion and growth of titanium nitride coating deposited on AISI 316L using cylindrical magnetron sputtering." *The Journal of Adhesion* (2024): 1-22.
6. Hans, Sukriti, Basanta Kumar Parida, Sebin Augustine, Vivek Pachchigar, K. P. Sooraj, and Mukesh Ranjan. "Anisotropic wettability transition on nanoterraced glass surface by Ar ions." *Journal of Materials Science* 59, no. 31 (2024): 14205-14223.
7. Kaur, Gagandeep, Puneet Negi, Ruhit Jyoti Konwar, Hemaunt Kumar, Nisha Devi, Gursimran Kaur, Ratan Boruah et al. "Tweaking the structural, micro–structural, optical and dielectric properties of anatase titanium dioxide via doping of nitrogen ions." *Ceramics International* (2024).
8. Savarimuthu, Infant Solomon Vinoth, Ramkrishna Rane, Paramesh Maila, and Alphonsa Joseph. "Microstructural and antibacterial properties of copper oxide deposited on polypropylene fabric by magnetron sputtering." *The Journal of The Textile Institute* (2024): 1-12.

Talks delivered

1. **Dr. Mukesh Ranjan** gave the **invited talk** title “Plasma processing for Semiconductor industries” at International Conference on Semiconductor Technologies-Material to Chip, scheduled to be held from 18-20/09/2024, at Amity Institute for Advanced Research and Studies (Materials & Devices), Noida.
2. **Dr. Tejal Barkhade** gave an o**ral presentation** on “Plasma Sterilization: Studies on Probable Mechanisms and Biochemical Actions behind Bacterial Inactivation” at 10th International Conference on Plasma Medicine (ICPM10) together with 9th International Workshop on Plasma for Cancer Treatment (IWPCT) during 8-13th September 2024 ***at Portorož, Slovenia***
3. Dr. Amreen Ara Hussain, gave a talk on “Enhanced Optoelectronic Devices Engineered with Lead (Pb) or Lead-Free Halide Perovskites Tailored for Environmental Stability” at International Conference on Energy and Environmental Materials (E2M-2024) at the Indian Institute of Technology, Indore during11-13 July 2024. She has received ***Best Presenter Award*** presented by WILEY Publisher.
4. **Dr. Mukesh Ranjan** gave an **Invited tutorial talk** title “Plasma for Material Processing and Industrial Applications” in the 10th Plasma Science Society of India - Plasma Scholars Colloquium 2024 (PSSI-PSC2024) being held from July 4 – 6, 2024 in the Lecture Hall Complex, IIT Delhi.

PUBLICATIONS / TALKS DELIVERED (in the last three months)



Dr. Tejal presenting at IWPCT, Slovenia

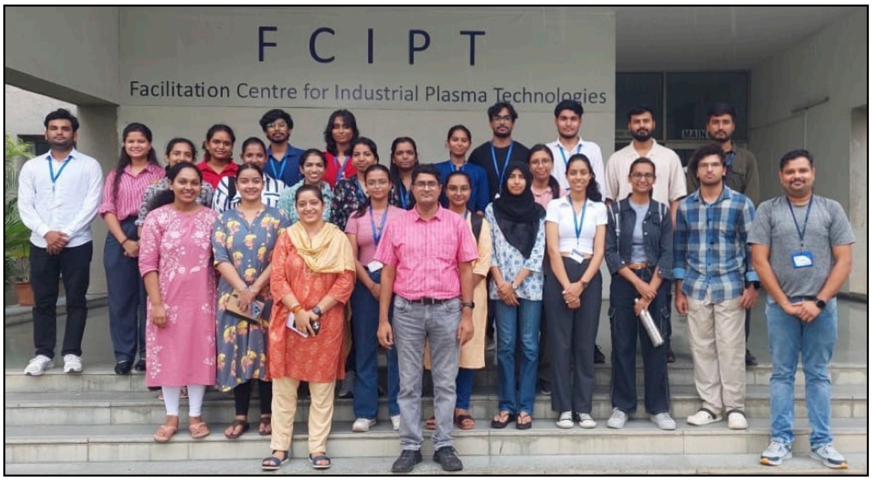
Dr. Mukesh Ranjan presenting at PSC2024, IIT-Delhi

Dr. Amreen presenting at E2M-2024, IIT-Indore; and receiving the award

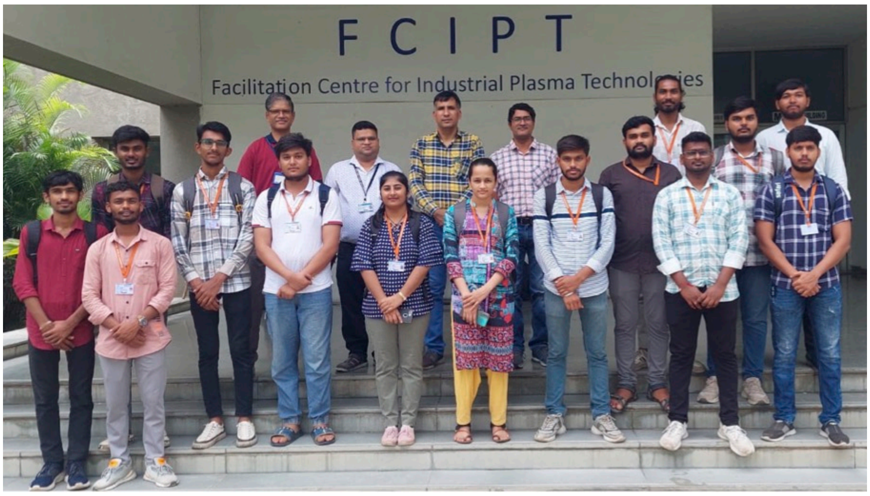
OTHER NEWS

Outreach Visits

A group of 25 B.Sc. students and faculty members visited FCIPT/IPR from National Forensic Science University, Gandhinagar on 22/08/2024.



A group of 14 B.Tech students and faculty members visited FCIPT/IPR from Gandhinagar Engineering College (GEC), Gandhinagar on 06/09/24.



Mr. Raj Kumar Thakur (Summer School Student IPR-2024) got the second prize for his summer project work title "Axial Plasma Diagnostics of Fireball Plasma Using Langmuir Probe ", He performed the work at FCIPT/IPR under the guidance of Dr. Mukesh Ranjan

OTHER NEWS

Swachchata Pakhwada

Under the 'Swachhata Hi Seva' program 2024, we celebrated 'Swachhata Hi Seva' campaign from 17th September to 1st October 2024 at Institute for Plasma Research. Under this campaign, as per the guidelines of DAE, various programs such as Pledge taking, walkathon, tree plantation, awareness talks etc., were organised at FCIPT campus also. A few pictures of the events are shown below.

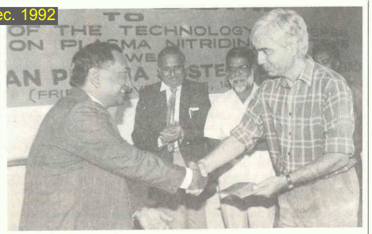








PPU: GLIMPSES THROUGH THE YEARS



Dec. 1992

Prof. P.K. Kaw, Director, IPR and Shri. Sohanlal Agrawal, Managing Director, IPCL exchanging technology transfer documents. Dr. P. Rama Rao, Secretary, DST and Prof. P.I. John witness the exchange

IPR TIES UP WITH INDIAN PLASMA SYSTEMS LTD FOR PLASMA NITRIDING TECHNOLOGY

"Materials Technology is one of the three thru

mber was a t-date for the ssing Group of ment for and transfer of ing technology tween the the newly Plasma Sys- dhinagar at a ded over by Dr. Secretary, f Science and overnment of of the technol- plications are e issue of the

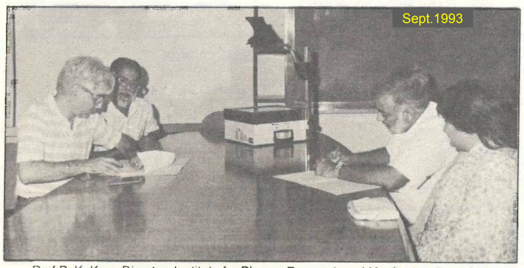
ocessing indus- ntry is undergo- ive shift in echnology base

Jan. 2018

. S.K. Nema, Prof Shashank Chaturvedi, Dr. Jayanti Ravi and Prof. P.I. John during panel discussion

while the yellowish lumps contain 92-94 % AlN.

AlN-Al Cermet materials often displays enhanced physical



Sept.1993

Prof P. K. Kaw, Director, Institute for Plasma Research and Mr. Sanjay Jhaveri of Micrometals signing the technology transfer documents.

Inaugural Session

Jan. 2023

Lightning the lamp

PAST

Shri Giriraj Singh, Minister of State for MSME, Govt. of India, visited FCIPT on 10th Oct 2017. He was accompanied by Shri Sanjay Hedaoo, Director - KVIC; Shri B. N. Sudhakara, Director – MSME Development Institute, Shri Jaikrishna, PS to MoS and other members of KVIC.

The Minister had visited the IPR stall at the Parliament House Annexe, New Delhi during 28th July to 11th August 2017 and had shown keen interest in using plasma technologies in areas of interest to MSME such as plasma nitriding for tool rooms etc.

The visitors were initially given a brief presentation about the technologies being develop FCIPT. They were then shown several of the technologies developed in-house.

Jan. 2018

Nitriding Facility

Nano Technology Lab

progress through CPWD, Varanasi. This facility will cater to various hospitals and healthcare facilities located in and around Varanasi to treat and dispose their biomedical waste in environment friendly manner.

April 2024

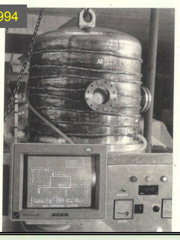
Dr. Shashank Chaturvedi (Director, IPR), Dr. S. K. Nema along with other officials during the stone laying ceremony

Jan. 2020

PTHS-2019 Delegates

India's first Plasma Nitriding Reactor for case hardening of industrial tools such as gears, cutting tools and extrusion dies. The technology has been transferred to M/s Indian Plasma Systems Ltd, a company established in Gandhinagar. The first

pipeline are: synthesis of aluminum nitride, a high value fine ceramic, fine metal and alloy powders, silicon dioxide deposition to produce anti-corrosion and diffusion barrier coatings, etching of plastics to increase printability etc.



March 1994

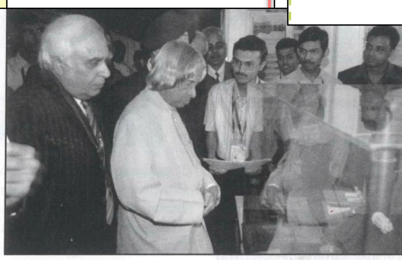
Other News

Inauguration of the FCIPT new building

FCIPT has recently celebrated the inauguration of i building, on 25th August 2010. The inaugural r cutting was performed by Shri Prof. P. K. Kaw, Di Institute for Plasma Research (IPR). The occasio also graced by other distinguished guests like Prof Dean, IPR; Prof. P. I. John, Chairman, Governing Co FCIPT etc.

Sept. 2010

ent between LPSC, ISRO and IPR



Jan. 2006

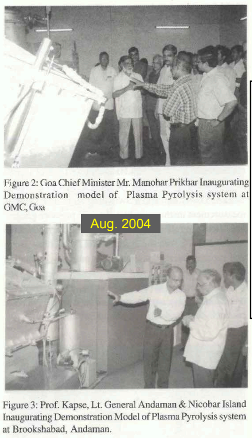
Centre for Industrial Plasma Tech

lasma Research, Phone (079) 23235018/ 23230908/

Sept. 1995

Mr. Y.S. Rajan and Mr. Deepak Bhatnagar of TIFAC at the IPR stall

ivities of the ASTW would allow us | to the development of technology



hemistry potential of toxic primary feeding oing on will be e gases ed using red was control models

Figure 2: Goa Chief Minister Mr. Manohar Prikhar Inaugurating Demonstration model of Plasma Pyrolysis system at GMC, Goa

Aug. 2004

system f March of Goa gure 2).

Figure 3: Prof. Kapse, Lt. General Andaman & Nicobar Island Inaugurating Demonstration Model of Plasma Pyrolysis system at Brookshabad, Andaman.

Plasma Nitriding System

Warm Welcome To Our New Director !!

Oct. 2016

Dr. Shashank Chaturvedi, Director, IPR

FCIPT Newsletter team would like to extend a very warm welcome to Dr. Shashank Chaturvedi (SO/H+), who took charge as the third Director of IPR on 5th August, 2016. Prior to taking charge as the Director of IPR, Dr. Chaturvedi was heading the Computational Analysis Division (CAD), BARC Facilities at Visakhapatnam. He has obtained his Phd from Princeton Univerisity in 1989. Some of the honours conferred on Dr. Chaturvedi are Institute Silver Medal at IIT Delhi (1985), Homi Bha-bha Science & Technology Award of DAE (2005), Group Achievement award of DAE and Elected as Fel-low of Indian Nation-al Academy of Engineering (INAE) in

Jan. 2017

Mr. J.H.Jangada, Technical Director, G.P Greens and Prof. Amita Das, Dean IPR exchanging tech-transfer documents

IPR PARTICIPATES IN IETF 95

Mar. 1995

A view of the IPR Stall.

The participation of the Plasma Processing Group of the Institute for Plasma Research in the 11 th Indian Engineering Trade Fair (IETF 95), also known as the International Industrial Fair of the East was very successful. The IPR stall was in Hall 6 which was part of the Technology Platform which was focussed to project indigenous applied research and innovative technologies, and where participation was by invitation. The exhibits consisted of a demonstration model for ion nitriding, a process developed by IPR for case hardening of indus- trial tools and components and

Dr. P. Rama Rao and Mr. S.K. Bijlani at the IPR Stall.

onal Institute, Dr. S. Chaturvedi, Director IPR and scientists from the IPR main campus. Here are some photographs taken during ion:

Jan. 2023

mittee members visiting FCIPT labs

Oct. 2019

Jan. 2017

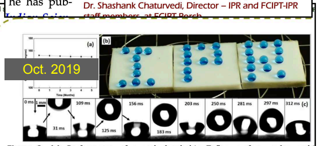
Mr. Aslam Moolji, Director AEPL and Dr. Chenna Reddy, Associate Dean, IPR exchanging Tech –Transfer documents.

PT-IPR Visit by NDTV Team

ntific corre- FCIPT– IPR 17. He visit- in the three racted with nd the vari- d here. He Jet, Plasma ano-Particle set-ups. he has pub-

April 2017

Mr. Pallava Bagla, NDTV scientific correspondent with Dr. Shashank Chaturvedi, Director – IPR and FCIPT-IPR staff members at FCIPT Porch



Oct. 2019

Figure 2: (a) Performance of superhydrophobic Teflon surface under ambi environment, (b) Photograph of spherical water droplets resting on superhydrophobic Te

Oct. 2016

Dr. D. C. Joshi, Dean, FPTBE, AAU, Prof. Dhiraj Bora ex- Director, IPR and Prof. Amita Das Dean, IPR, (Left to Right)

Technology Transfer : Nano Powder

oxide nano powders have immense applications in varied fields like pharma , paint, automobile industry, textile etc. These are high value powders and are at demand for specific applications. There aren't any known Indian industries cing these Nano powders; they are mostly imported or produced with imported machines.

Oct. 2016

The tech-transfer documents being exchanged between Dr.S.Mukherjee, and Dr.Venkat Ramani

PPU: GLIMPSES THROUGH THE YEARS

EDITOR'S NOTE

This issue of the newsletter introduces an emergent area of plasma technology which has already made global impact, namely pollution control. The relevance to India already committed to rapid industrialisation is topical and we hope that the Science and Technology Advisory Committees associated with the relevant ministries will take note of these developments.

An article by Mr. M. A. K. Babi of the Indian Plasma Systems Ltd on bond-coat techniques poses the interesting possibility of combining the fruits of non-equilibrium plasma technology in terms of film-coating techniques with the commercialised plasma spray coating technology.

We also include a report by Dr. B. N. Ganguli on the series of TIFAC-sponsored regional workshops on surface engineering. Readers may be interested to know that one of the positive outcomes of these workshops was the decision to publish a newsletter devoted to the problems of surface engineering in the Indian context.

- Prof. P. I. John
Plasma Processing Group

September 1994

PTBT-2017
Sponsored By - Board of Research in Nuclear Sciences
7th -8th December 2017
Institute for Plasma Research (IPR)
Gandhinagar

Jan. 2018

P.I. John, Padma Shri awardee and ...der of FCIPT, Prof. Abhijit Sen and Prof. Y. ...xena, members of FCIPT council, Prof. K.S. ...esh Prasad and Prof. S. Mukherjee former ...ion heads of FCIPT were the dignitaries ...ed. The chief guest for this event was Dr. ...nti Ravi, Health commissioner of Gujarat ...ernment. More than 65 participants from ...stries and academia attended the ...posium. The program started with a ...ome address by the convener followed by ...oming the distinguished guests with a ...uet of flowers. The event started with ...ing of the ceremonial lamp by the ...nguished guests. This was followed by the ...itation ceremony by IPR Director Prof. ...hank Chaturvedi where he felicitated our ...nguished guests with shawls and

...novations by Scientific Ministries and ...dia

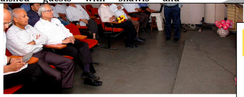
Oct. 2017

Dr. Sanjay Jaiswal (Loksabha MP) (seated) and Shri Giriraj Singh (MP and Minister of State - MSME) (seated) being briefed about plasma textile and plasma pyrolysis technologies

Shri Narendra Modi awarding the prestigious Vikram Sarabhai award to Dr. K.S. Ganesh Prasad and Dr. S.K. Nema.

April 2005

On May1 2005, Shri Narendra Modi, the chief minister of Gujarat awarded the pretigious award in a well organized function at Bhavnagar. This contribution by Dr. K. S. Ganesh Prasad and Dr. S.K. Nema were adjudged to be creative, cost effective and commercially successful, thus contributing to the growth and prosperity of Gujarat. Facilitation Center for Industrial Plasma Technologies is proud of these scientists who have been conferred with this award.



Dr.S. K. Nema, giving a technical presentation about the plasma application in textile

July 2014

Demonstration of plasma treatment system developed by DST funding

Times of India, Ahmedabad - 5th May

Centre gives nod to plasma tech for waste incineration

Jul. 2016

PLASMA POWER

Ahmedabad: It took six years and several trials to convince the ministry of environment and forests (MoEF) of the environmental advantages of plasma pyrolysis — breaking down of biomedical and municipal solid waste to by using plasma. The process breaks down any form of waste to water, carbon monoxide, hydrogen and methane. These gases can be harnessed to produce energy.

Times View

The Pirana dump will soon be turned into a garden. But that's not a solution. Every day Ahmedabad generates 4,200 metric tonnes of unsegregated waste, out of which just 700 metric tonnes gets recycled or converted to useful refuse-derived fuel pellets. This forces the AMC to stack up tonnes of waste into landfill sites. This will only create another Pirana-like dump. Its high time that AMC ensures enforcement of stringent waste segregation rules and employ ...

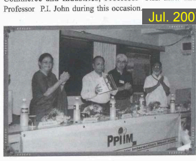
Releasing of the 50th issue

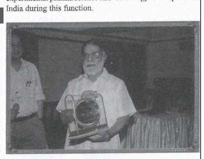
Plasma Processing Interaction Meet PPIIM-2006 was organized on 27-28th July, 2006 at Institute for Plasma Research, Gandhinagar, Gujarat. The 50th issue of the "PLASMA PROCESSING UPDATE" was released by Shri. R. J. Shah, the Principal Industrial Advisor to Govt. of India in midst of other distinguished guest like Mrs. Paru Jaykrishna, Senior Vice President of Gujarat Chambers of Commerce and Industries, Professor P.K. Kaw and Professor P.I. John during this occasion.

...of discussion during this meet. During the panel discussion it has been brought out by most of the participants that such types of meet should be frequently organized to promote awareness of plasma processing to the industries. It was also pointed out that in addition to such meet, efforts can be taken to organize seminars by subgroups in different application areas.

Professor P. I. John, who was the first editor of this update was honoured for his outstanding contributions to experimental plasma science and technology development in India during this function.

Jul. 2007





The main objective of this meet was to bridge the gap between the institute and industries and thereby to exploit the potential of plasma technology for industries. Further, ...

Non Thermal Plasma Treatment on TPO Extruded Channels

Other news

Installation of two experimental systems at Kathmandu University, Nepal

Two experimental systems, Paschen Curve system and Double Langmuir Probe system were developed and successfully installed & commissioned at Kathmandu University, Nepal in January 2013 by FCIPT. The images below are the actual systems installed at Kathmandu University

Jul. 2013

Photograph of Paschen Curve system

Photograph of Double Langmuir Probe Diagnostics system

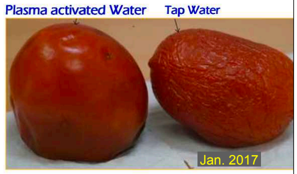
Plasma Pyrolysis system installed at Hyderabad, Andhra Pradesh

FCIPT has installed two more prototype plasma pyrolysis systems for disposal of plastic and medical waste in G.B. Pant Hospital, Agartala and Gandhi Hospital, Hyderabad (Fig. 1) under the technology demonstration and promotion program of DST, New Delhi. The system disposes the waste in an environment friendly manner with the emission levels lower than the norms given by CPCB for incinerator technology. Plasma pyrolysis is a technique of disintegrating the longer chains of carbonaceous material for example, cellulose, plastic, etc. into lower hydrocarbon and other combustible gases form, for example CO, CH_4, H_2, ... higher than 650°C in the prima... gases flow through a second... induced draft fan where air ... combustion. The temperature ... 1000°C. The residence time ... around 1sec which is sufficient ... formed in the primary chambe... etc. The flue gases after secon... unit where the temperature of ... hot gas is then thrown in atmos... chimney. The required height ... less than 7 meters. The system ... hour.

May 2008

Fig. 1: Prototype plasma pyrolysis system for disposal of actual plastic ... and data collection in Gandhi hospital, H...

Dec. 2021



Jan. 2017

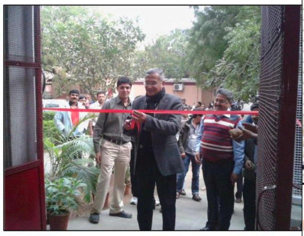
Washed Tomatoes after 40 days

Marcelli... the Scien... ANCM & NEEM) and Dr. S. Mukherjee. There were 14 lectures delivered by 12 speakers from India (RRCAT, SINP, IUAC), Italy, France, Japan and USA.

Jan. 2014

Inauguration of NEEM-2013

plant on 1st Jan 2015. This plant also serves th... purpose of technological demonstration on a... actual scale.



Prof. Bora inaugurating the plasma Pyrolysis Plant a... IPR

Oct. 2015

Oct. 2016

...r. A. Vardhrajulu ,Chairman TT,IPR ,Dr. Shashank Ch... ...urvedi, Director IPR and Mr. Ashok Vora ,Bhakti Ener... ...eft to Right) exchanging tech-transfer documents

PLASMA PROCESSING UPDATE

ZIRCON FURNACE Becomes Operational

The Plasma route will reduce the number of steps involved in the dissociation process, thereby making the process economically more attractive.

Jun. 1995

Media Coverage in Leading Newspapers

Oct. 2015

THE TIMES OF INDIA

IPR wizardry gives Isro satellites space shield

Plasma beams: Eco-friendly tool for industry, agriculture

Now, plasma to sanitize your greens?

ગુજરાત સમાચાર

http://www.plasmaindia.com/News%20letter/articles/ToI-Plasma_Beam.jpg

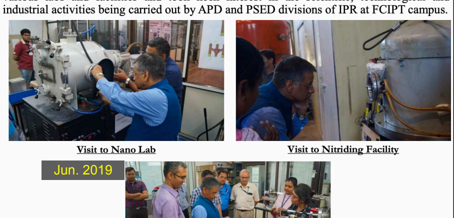
કૃષિ અને મેડિકલ ક્ષેત્રે પ્લાઝ્માનો વપરાશ કાંતિ સર્જશે

દિવ્ય ભાસ્કર

Facilitation Center for Industrial Plasma Technologies
Institute for Plasma Research

Plasma Pyrolysis System Functional at IPR

Shri. Gopal Baglay, Joint Secretary to PM, visited FCIPT on 12th April 2019. He was accompanied by Dr. Shashank Chaturvedi, Director IPR, Shri. Ujjwal Baruah, the then Dean IPR, Dr. Nirav Jamnapara, Head of the Plasma Technology and Transfer Section and few other dignitaries from Space Applications Centre, ISRO. During his visit, he toured various labs and facilities and took keen interest in the scientific, technological and industrial activities being carried out by APD and PSED divisions of IPR at FCIPT campus.



Visit to Nano Lab

Visit to Nitriding Facility

Jun. 2019

Installation of Plasma Pyrolysis system at Government Medical College, Srinagar for demonstration of Biomedical waste disposal

A prototype plasma pyrolysis system for demonstration of Biomedical waste disposal with disposal rate of 15 kg/hr was installed and commissioned at Government Medical College, Srinagar in the month of May 2013. This system was funded by Department if Science and Technology (DST), New Delhi and the fabrication was done by M/s. Bhagwati Pyrotech Pvt Ltd. along with FCIPT, IPR. The photograph of the actual system installed is shown below.

Jul. 2013

Photograph of Plasma Pyrolysis system installed in Srinagar

Apr. 2024

moving with 6mtr/min can be treated online to modify the surface. The active species formed in the plasma dissociate and chemically bond with polymer surface. These species attach or react with the surface, graft the functional group and therefore change the surface properties of polymer. The non - thermal plasma treatment system consisted of an array of A.C plasma torches to modify the surface as shown in figure 1.

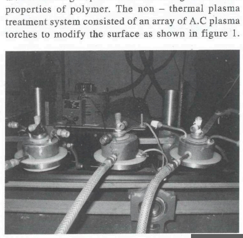


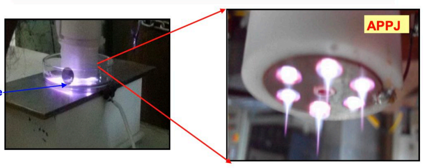
Fig.1: Array of non thermal plasma torches

Jul. 2007

These days, non-thermal plasmas found their applications in variety of biomedical and agricultural ... grades the concentration of pesticides and does not affect the bulk properties of vegetables.

Jan. 2016

Dicholorvos removal in Cabbage by Multiple Plasma Jet



Oct. 2023

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